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ENHANCED PERFORMANCE USING PHYSIOLOGICAL FEEDBACK

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The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*
Four studies are described designed to investigate (1) the use of blink variables to predict errors in vigilance performance, (2) the relationship between blink latency and decision making, (3) the factors affecting blink latency in a cognitive task, and (4) head and eye movements in acquiring peripheral information. In the first experiment, blinks were not found to be associated with error stimuli any more than they were with correct stimuli. The second experiment investigated the hypothesis that blink latency following a discriminative stimulus is a function of the time at which the decision could be made. Blink latency varied with the duration of the target stimulus, confirming the hypothesis. The third study investigated factors influencing the reduction in blink latency over trials. Components of the response sequence were isolated experimentally. Results suggested that the reduction in blink latency is due to an improvement in the implementation of the instructional rule. In the final study, head and eye movements were studied while subjects responded to peripheral stimuli. The proportion of the gaze shift accomplished by a head movement increased with task difficulty. Also, prior information about the time required by the task affected saccade latency to the peripheral stimulus.

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ENHANCED PERFORMANCE USING PHYSIOLOGICAL FEEDBACK

INTRODUCTION

There is now substantial literature to the effect that blinks are not randomly distributed in time (for a review, see Stern, Walrath & Goldstein, 1984) but are related to task variables and the cognitive processes such demands invoke. Some studies have shown, for example, that blink rate is affected by time on task, although there is some divergence of opinion as to the nature of the effect. Some claim an increase with time (e.g., Carpenter, 1948; Hoffman, 1946) and others, no effect at all (Brezinova & Kendell, 1977; Goldstein, Walrath, Stern & Strock, 1985). Apparently, the variables controlling this effect have not yet been determined. A possible resolution of these conflicting data has been couched in terms of the temporal pattern of stimuli interacting with the difficulty of the task (Bauer, Strock, Goldstein, Stern & Walrath, 1985).

Going beyond blink rate, studies conducted in this laboratory and others' (e.g., Goldstein, *et al.*, 1985; Bernstein, Taylor, Weinstein & Riedel, 1985; Orchard and Stern, 1991) have demonstrated that the points in time at which blinks occur and the characteristics of those blinks reflect the cognitive demands of a task. Blinks become progressively shorter, as well as more infrequent, for example, as an imperative stimulus approaches, with the result that immediately before and during the stimulus there is an inhibition of blinking. Those that do occur are brief in duration, and, further, this inhibition typically extends through the period during which a response is being generated and executed (Bauer, Goldstein & Stern, 1987).

The interpretation of this relationship between cognitive activity and the parameters of the blink seems to almost force itself upon us (which, by itself, seems a reason to be cautious). Namely, as an imperative stimulus approaches, attention is being mobilized to facilitate its apprehension. Since blinks might interfere with this process (cf., the phenomenon of blink suppression: Wibbenmeyer, Stern & Chen, 1983), they are inhibited. This argument seems very reasonable and near obvious when applied to visual input. The fact that this inhibition also occurs when the stimuli are auditory (Bauer *et al.*, 1985) suggests that the blink may be the reflection of a more general source of interference than simply one of visual occlusion.

The present project is based on the assumption that the inverse relationship between attention and blinking, described above, is a causal one. The premise is that if blink inhibition reflects attentional mobilization, then the obverse may also be true, viz., the occurrence of blinks should be a marker for attentional lapses. Since blinks do occur obligatorily even at times when individuals are attending, and especially when attention must be maintained for an extended period of time, this relationship could not be perfect. Nevertheless, blinks should be useful in predicting when attention is waning.

EXPERIMENT 1a

The first experiment was designed to test the inference that blinks might be utilized to signal periods of inattention. For this purpose, it was necessary to select a task in which lapses, or dropouts, in performance would not be rare. The task selected has been used in this laboratory and meets this criterion. It requires discrimination between the durations of two tones. It is our contention that the requirement to discriminate between two (or more) durations requires more in terms of attentional resource allocation than the discrimination between tonal qualities. In the latter case, "attending" for a only a brief portion of the stimulus would be sufficient to make the discrimination. To make a duration judgment, on the other hand, it is necessary to be attentive not only to the onset of the stimulus but also to maintain that attention for the full period of the stimulus.

So that every subject would show the desired decrement, and thus contribute useful data to test the hypothesis, several levels of difficulty were used. In this way, two functions could be served. First, the effect of difficulty could be evaluated on blink parameters, and second, for each subject, at least one level would be sufficiently difficult to produce the necessary performance decrement over time.

Methods

Subjects. Eighteen Washington University undergraduates were paid for their participation in this experiment.

Apparatus. Sessions were conducted with subjects seated in a sound-attenuated room, isolated from the experimenter and the equipment. Stimulus delivery was controlled by an LSI 11/23 microcomputer. Mounted on the arm of the subject chair was a microswitch. Attached to the arm of the microswitch was a small finger-shaped cage into which the subject's index finger was inserted. In subsequent studies, the microswitch response system was replaced by a contact device consisting of a low chassis box (5-cm high) on which there was mounted a 2.5 x 1.5-cm flat metal contact switch

plate. The chassis box was placed on the table in front of the subject. When the subject's index finger was placed on the plate, a circuit was completed through a wrist strap to the ground of the plate circuit. Lifting the finger from the plate produced a voltage deflection on the polygraph.

Pure tones (15 kHz) were presented through a speaker located directly in front of the subject.

For electrooculographic (EOG) analysis, five electrodes were applied to the face of each subject. One pair was centered above and below one eye (for vertical eye movements and blinks). Another pair was applied lateral to the outer canthus of each eye (for horizontal eye movements). The fifth electrode (ground) was placed in the center of the forehead. Signals from these electrodes were passed to special purpose EOG amplifiers and, together with stimulus and response information, were stored on analogue tape for later analysis.

Procedure. A pilot study with 5 subjects was run to select the three difficulty levels. Four difficulty levels were chosen for this purpose. Subjects were presented with 102 stimuli at each level, requiring approximately 6 minutes per level. The final three levels were chosen so that none of the tasks would be so difficult that performance would be near chance, or so easy that errors would be rare. Following these guidelines, the tone pairs selected were, from easy to difficult, respectively, 270 and 430 ms, 300 and 400 ms, and 310 and 390 ms. In all cases the short-duration tone served as the "target" tone, that is, the tone to which the subject was instructed to respond by lifting the finger from the microswitch. The target tones were presented randomly in the ratio of 1:2 relative to the longer or nontarget tones. The interstimulus interval was constant at 3 seconds.

After electrode application, a brief practice session was run to provide a perceptual frame of reference for judging the stimuli. It consisted of 20 tones, alternating between long and short. After the practice tones, the subject was asked if the procedure was clear, any questions were answered, and the test was begun. The test session consisted of 702 stimuli taking approximately 40 minutes. Each subject received all three difficulty levels on 3 days. Order of difficulty level was counterbalanced so that three subjects were run on each of the six orders of the three levels.

Data Reduction. Four channels of data were recorded both on stripchart and on analogue tape for subsequent reduction. These channels were vertical EOG, horizontal EOG, stimulus and response information. Following the experiment, these data were amplified, digitized, and transferred to a VAX minicomputer. The digitized data were then automatically and/or manually reduced. The reduced data were then output

on hard copy, which included the temporal relations of the different events to each other: their onset, offset and durations. Tabulations were also provided of blink durations as a function of delay following stimulus onset, blink latencies, blink amplitudes, and blink durations.

Three 5-minute segments of each 40-minute task were digitized. These 5-minute segments started at 5, 16, and 35 minutes into the 40-minute run, representing the early, middle and late portions of the task, respectively.

Data Analysis. The data were subjected to analyses of variance (ANOVA). The degrees of freedom were adjusted using the conservative Greenhouse-Geisser adjustment.

Results

The results of the analysis of the various performance and physiological measures will be presented first to document the validity of the procedure and the rationale for the subsequent procedures.

Performance Measures.

Hit Rate and False Alarm Rate. Raw Hit rates and False Alarm rates are presented in Table 1 (these values were arc-sine transformed for analysis). Hit rate was significantly affected by task difficulty, there being fewer hits in the more difficult tasks ($p < .01$). The lower Hit rate associated with the more difficult tasks was not due to a general response inhibition because there was not a significant effect of difficulty on False Alarm rate ($p = .06$). As for time-on-task, both Hit rate ($p < .01$) and False Alarm rate ($p < .01$) decreased with time. No interactions were significant.

Table 1. Experiment 1 - Hit Rate (% trials), False Alarm Rate (% trials) and Reaction Time (in ms), as a function of difficulty and time on task.

	Difficulty Level								
	Easy			Moderate			Difficult		
Time	Ear	Mid	Lat	Ear	Mid	Lat	Ear	Mid	Lat
Hit Rate	96.7	94.4	92.9	87.8	78.3	73.7	81.7	72.9	71.3
FA Rate	.012	.006	.008	.032	.009	.013	.087	.064	.040
RT	378	386	401	435	472	468	450	481	468

Reaction Time. Also displayed in Table 1 is Reaction Time (RT), which was significantly related to difficulty

($p < .01$), as expected, but was not affected by time-on-task ($p = .09$).

The combined results concerning performance measures confirm that the difficulty and time-on-task manipulations were successful.

Response duration. Response duration was not affected by time-on-task ($p = .24$) or difficulty level ($p = .87$).

Physiological Measures.

Blink Rate. Blink rate was expressed as the number of blinks per minute that the eyes were open. These data are presented in Table 2. Rate increased significantly with time on task ($p < .05$), but not with task difficulty ($p = .46$). Paralleling these blink rate effects were those of time on task and difficulty on the number of blinks occurring during the stimulus itself. As was true for blink rate, the frequency of such "stimulus blinks," displayed in Table 3, also was found to increase with time on task ($p < .05$) but not with difficulty ($p > .40$).

Table 2. Experiment 1 - Blink rate (blinks/min) as a function of difficulty and time on task.

	Difficulty			
Time	Easy	Moderate	Difficult	Mean
Early	22.9	25.6	22.8	23.79
Middle	24.2	25.3	26.2	26.32
Late	24.8	28.0	27.3	26.70
Mean	23.96	[illegible].32	25.43	25.24

Table 3. Experiment 1 - Frequency of blinks occurring during stimulus presentation, as a function of difficulty and time on task.

	Difficulty			
Time	Easy	Moderate	Difficult	Mean
Early	2.6	3.8	2.4	2.96
Middle	2.9	3.8	4.0	3.57
Late	4.3	4.5	4.4	4.41
Mean	3.28	4.06	3.61	3.65

Blink Latency. Blink latency as a function of task difficulty, trial type, and time on task is displayed in Figure 1. ANOVA indicated that latency decreased significantly with time-on-task ($p < .05$). Latency was also a function of the type of trial the stimulus followed; latency was longer following HIT trials than Correct Nonresponse (CNR) trials ($p < .01$). Note that in this study, latencies were taken from stimulus offset. Thus, when the nontarget (long) stimulus was presented, the discrimination decision could be made before the stimulus terminated. If the blink is related to the decision process, this would have the effect of shortening blink latency to the nontarget stimulus, as was the case. Consistent with this argument, the <u>duration</u> of the target stimulus was added to the nontarget <u>latency</u>. The result was to reduce the difference between target and nontarget latencies, on the average, to about 50 ms and render the HIT/CNR difference insignificant.

There was no effect of task difficulty ($p = .32$), nor were any interactions significant.

Blink Duration, Amplitude, and Closing Duration. None of these variables was affected by task difficulty or time-on-task.

Long-Duration Eye Closures (LDCs). LDCs are differentiated from eye blinks in that the duration of LDCs exceeds 500 ms. These data are presented in Table 4. Once again, the number of LDCs increased significantly with time-on-task ($p < .01$), and again difficulty had no effect ($p =.33$). The total amount of time that the eyes were closed ("total closure time") showed the same pattern as the above three measures, increasing significantly ($p < .05$) with time-on-task, and remaining unaffected by difficulty ($p = .53$).

Table 4. Experiment 1 - Frequency of long-duration closures (LDCs) as a function of difficulty and time on task.

	Difficulty			
Time	Easy	Moderate	Difficult	Mean
Early	1.17	1.50	2.00	1.56
Middle	3.83	3.44	3.06	3.44
Late	3.39	5.89	7.17	5.48
Mean	2.80	3.61	4.07	3.49

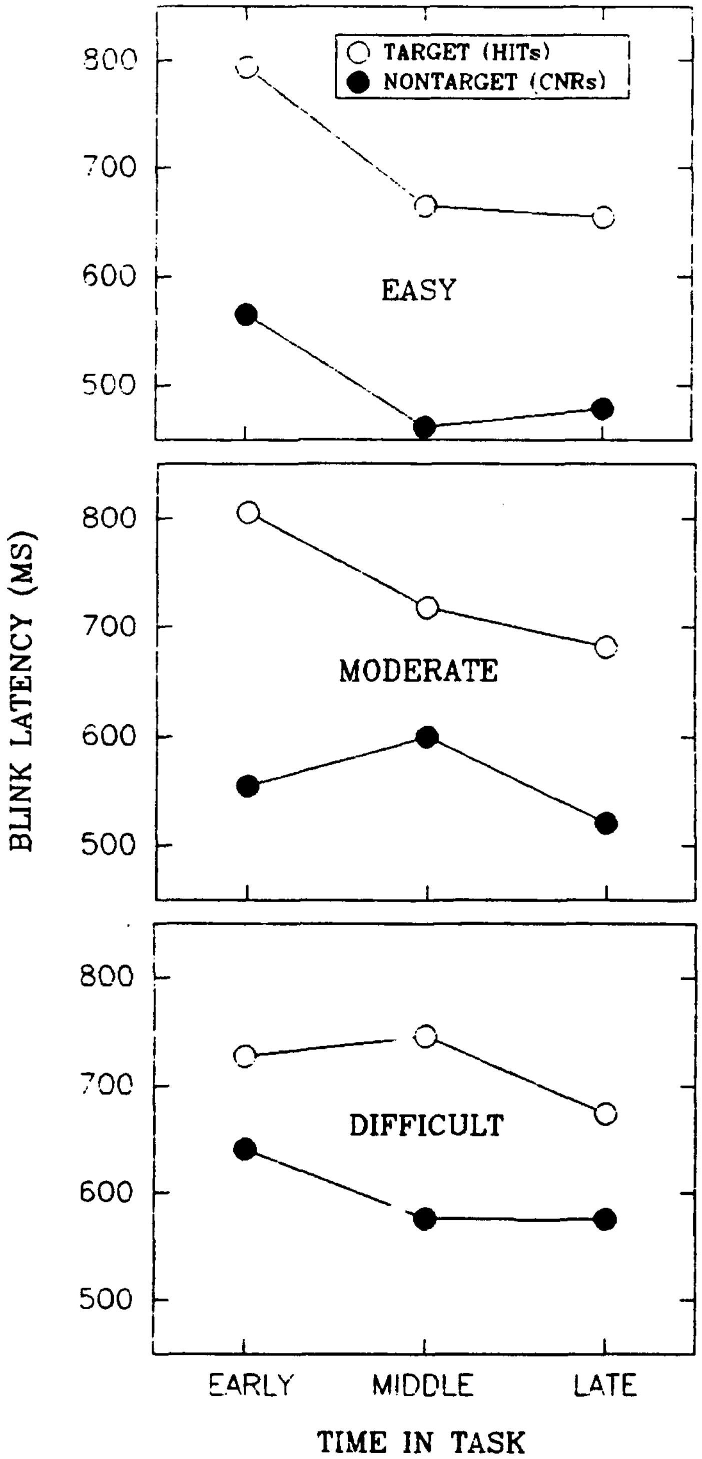

Figure 1 Experiment 1 – Blink latency as a function of task difficulty, trial type, and time on task.

Discussion

The time-on-task effects on blink latency replicated earlier findings, but the absence of a difficulty effect on blink latency, or, for that matter, on any of the other EOG variables, was not consistent with earlier work (Bauer, et al., 1987; Bauer, et al., 1985). Examination of the difference between this and other studies suggests an explanation for this discrepancy. The present duration discrimination task is essentially a perceptual task, while the previous tasks, where blink latency increased with task difficulty (Bauer, et al., 1985), were considerably more cognitively loaded. Blink latency, accordingly, may only be affected by cognitive activity, and, perhaps more important, by activity that requires retention and/or manipulation of information. In fact, it may be that the time required by such activity is the critical factor. In contrast, perceptual factors, although variable in difficulty, require no complex time-consuming internal processing. The subject either can or cannot discriminate the durations, and additional time to draw on and manipulate stored information would not be of help. Thus, differences due to difficulty, with respect to the time taken to come to a decision, are inconsequential. There is, however, a fly in this theoretical ointment; RT did increase with difficulty. But discrepancies between RT and blink latency are not rare. In previous studies, a somewhat paradoxical disagreement between the two variables existed in that RT increased with time-on-task, while blink latency decreased over the same period. In the present study as well, blink latency again decreased with time-on-task. While the RT effect did not achieve significance, it nevertheless increased over time. These results suggest clearly that the processes controlling these two variables are not redundant.

Concerning these time-on-task effects on blink latency, the results, in other respects, are also consistent with previous findings. Blinks typically have been found to be inhibited during the task stimuli, and they were here, at least initially. As the task progressed, however, the subjects' ability to remain attentive waned (the decline in both HIT and FALSE ALARM rates is viewed as a general reduction in responsiveness), and with it, there was a breakdown in their ability to inhibit blinking.

This breakdown of blink inhibition with time-on-task was manifested in several ways. First, blink rate increased. Second was the increase in both the number of long-duration closures and the total closure time. And finally, blink latency, presumably reflecting the deferral of blinks during stimulus input and processing, decreased. The end result of the latency decrease was that blinks began increasingly to impinge on the task stimuli. An alternative interpretation of the latter effect is based on the observation, alluded to

above, that the processes that control reaction time and blink occurrence are not redundant. This view holds that some component of the decision process is increasing in efficiency as time progresses, and it is upon the completion of this process that the blink inhibition is relaxed. Since this process is in the sequence leading up to the manual response, it would produce a correlation between blink latency and reaction time. But other processes associated more specifically with the programming and execution of the response would be overlaid on these prior processes. The data, interpreted in this way, would suggest that the response-related processes increase in duration over time sufficiently to compensate, or overcompensate, for the increasing efficiency of the prior process. The net result is an increasing RT over time in association with a decreasing blink latency.

EXPERIMENT 1b

Given confirmation of the apparent relationship between blink occurrence and attention, especially the movement of blinks toward the stimulus with time-on-task, the stage is set for an examination of our original question. That is, if blinks following stimulus onset are occurring increasingly early over trials, and, at the same time, the number of performance errors is increasing, the question is whether the occurrence of a blink in close temporal proximity to a stimulus will be a predictor of a dropout in performance. For this purpose, an algorithm was devised to scan the taped record and flag trials on which blinks occurred during a specific temporal window around the stimulus. Initially, this window extended from 400 ms before to 400 ms following the stimulus. The data for a single difficulty level for each of four subjects were selected to be assessed by this algorithm. This selection was based on an initial high level of performance coupled with a substantial drop over time. The results were not encouraging; an excessive number of Hit trials were associated with blinks.

Accordingly, the width of the stimulus window was narrowed so that to qualify as being associated with a stimulus, a blink had to actually occur during the stimulus. The results were no more encouraging. Table 5 presents this analysis for both Target trials and Nontarget trials. As can be seen, target error trials associated with a blink were missed 41% of the time, which was almost the same rate as target error trials not associated with blinks: 42%. With respect to nontarget stimuli, there were too few false alarms to produce any usable data. Blinking in or around a stimulus does not seem to be associated with poor performance. Another avenue of exploration concerned the relationship of LDCs to errors. This possibility was investigated on a relatively molar level, assessing the correlation between overall LDC frequency and total errors.

Although subjects were found to maintain their relative standing with respect to the number of LDCs that they showed over the course of the task, the number of LDCs was not highly related to performance. Correlations between the number of LDCs and the number of misses on the three experimental days were r = .22, .01 and .15, none statistically significant. Thus, while there may be some intra-subject consistency in early and late LDC rates, the LDC rate is not associated with performance.

Table 5. Experiment 1b - Percentage of target and nontarget error trials, as a function of whether the trial was associated with a blink.

	Target		Nontarget	
Subject	Blink	Nonblink	Blink	Nonblink
1	37	55	0	1
2	57	33	0	13
3	43	43	0	0
4	28	38	2	0
Mean	41.2	42.2	0.5	3.5

EXPERIMENT 1c

Though blinks might not be predictive of errors when the only blinks considered are those in close proximity to target stimuli, it is still possible that blink events in the interstimulus interval (ISI) might yield information as to the attentiveness and preparedness of the subject for the subsequent stimulus. In an attempt to explore this possibility, blinks were resorted depending on whether the next trial was a hit or a miss.

Methods

Blink latencies prior to miss trials, and an equal number of hit trials, were manually extracted from the early and late portions of the easy and difficult tasks. The time and difficulty dimensions were collapsed. Hit trials were selected on the basis of their proximity in time to the miss trials so as to match trials for general level of alertness. Blinks in the 3-sec ISI were sorted into thirty 100-ms bins. As can be seen in Figure 2, the findings again did not support the hypothesis; the regression lines for the hit and miss conditions converged to a point as the next trial approached.

A similar analysis was performed for blink durations. The assumption again was that this measure, which in earlier studies (e.g., Bauer, et al., 1987) decreased as the criti-

cal stimulus approached, might be a more sensitive indicator of attentional mobilization than blink frequency.

Results

As can be seen in Figure 3, there were no noticeable differences between blink duration patterns leading up to hits and those preceding misses. To complicate matters further, blink duration did not decline over the interval as it had in previous studies, although in those studies, the tasks were considerably more cognitively loaded, had a different ISI than the present study, and were visual rather than auditory. Which of these factors is relevant cannot be determined at this time but it is difficult to conceive of any for which the hypothesis should be changed.

Discussion

These data present a paradox. On the one hand, they replicate the decline in blink rate over the interstimulus interval, reinforcing the hypothesis that this decline is causally related to the degree of attention. At the same time, if the interpretation is to be consistent with the hypothesis that blink inhibition does index attention, then the conclusion would have to be that the misses are not due to attentional lapses since the pattern and characteristics of blinks leading up to a miss is no different from those leading up to a hit. Perhaps the problem is that there are different types of misses, not all of which are predicted by blink occurrence. Clearly there is one type of miss, which we may call a "perceptual" miss, that is due to the difficulty of the discrimination. This type of miss is distinct from the miss that results from an attentional dropout. While blink occurrence might be predictive of the dropout type, it would be irrelevant to the perceptual type. Unfortunately, both types were included among the miss trials in the earlier analysis.

The problem, then, is to differentiate the two types of misses. It would appear that the difficult task, which includes a greater number of perceptual misses, would not be the optimal one for this analysis. Nor, for similar reasons, would the earlier part of any task be optimal if there were any number of errors committed at that time since these are more likely to be of the perceptual type. With these considerations in mind, a test of this interpretation could be based on misses selected according to the following criteria: (1) They must come from only those sessions in which few misses were made early in the session, and (2) from those misses meeting the first criterion, only those misses will be accepted that are in the late period of that task.

Using these criteria, blink distributions were plotted for the intertrial interval leading up to hits and misses. As was the case for unselected miss trials, there were again no apparent differences between these blink distributions.

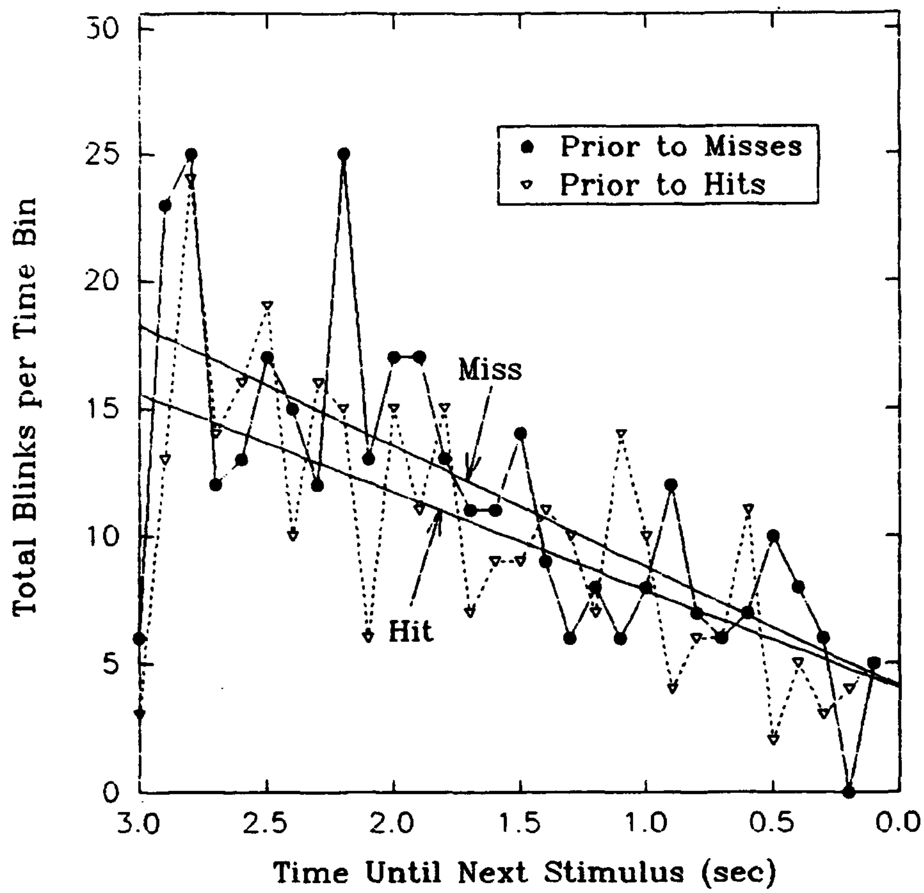

Figure 2. Experiment 1c – Blink frequency in the ISI prior to HITS and MISSes. Zero time represents onset of the stimulus. Overlaid lines are regression lines, as labelled.

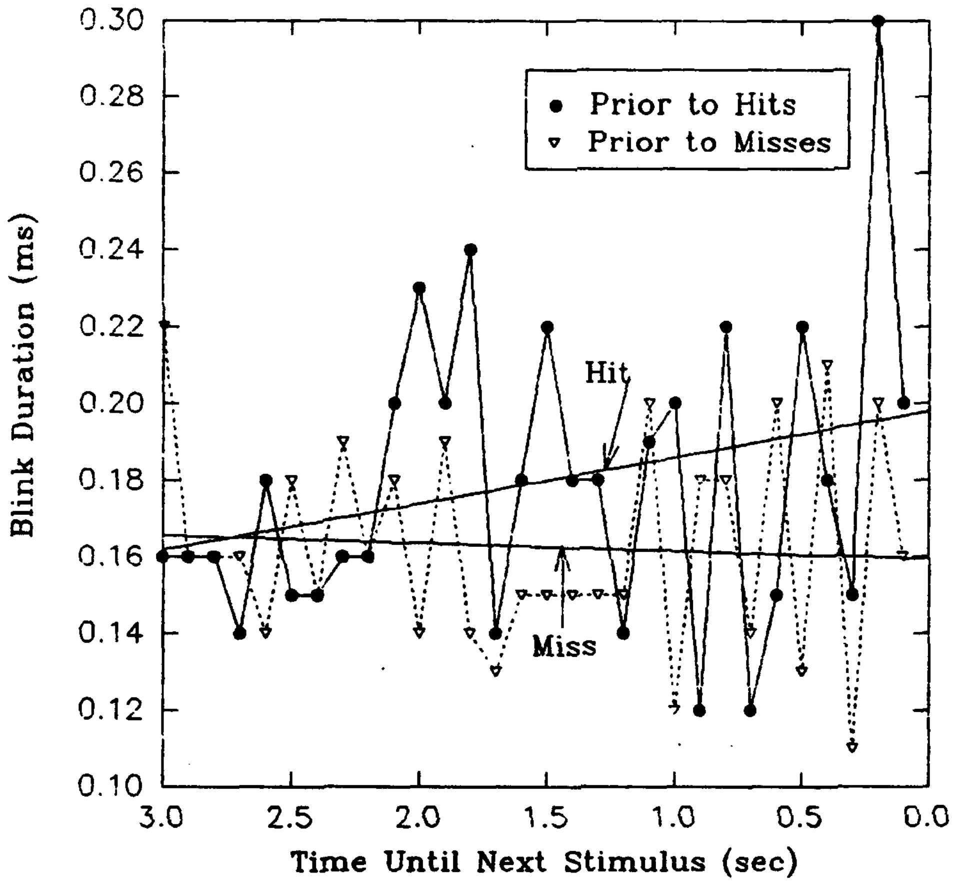

Figure 3. Experiment 1c – Blink duration in the ISI prior to HITs and MISSes. Zero time represents onset of the stimulus. Overlaid lines are regression lines, as labelled.

EXPERIMENT 2

In the first experiment there was no effect of task difficulty on blink latency in contrast to the results of previous studies where difficulty effects on blink latency were evident. If blinks are predictors of the onset and termination of cognitive processes, what can account for this inconsistency? It has been our working hypothesis, and the data have supported it, that blink timing is related to decision processes. In a given duration discrimination task, we have hypothesized that the blink following the longer of two tones is deferred until after the discrimination is made. The discrimination cannot be made for a long stimulus, however, until the duration of the short stimulus in that task has been exceeded by some just-noticeable increment. In the first experiment, the difference between the short and long durations for the easy discrimination was 430 - 270 = 160 ms. The analogous differences for the moderate and difficult levels there were 400 - 300 = 100 ms and 390 - 310 = 80 ms, respectively. If blink timing is sensitive to stimulus duration rather than difficulty *per se*, then the entire spread of duration differences, from 160 to 80, or a spread of 80 ms, may not be sufficiently great to discriminate in the blink latency.

The present study was designed as a direct test of the hypothesis that the time consumed by decision processes determines blink occurrence. The spread of differences between target and nontarget stimuli in the tasks of this study was chosen to allow difficulty to be manifest in blink timing. The durations of the longer (nontarget) tones in all tasks were identical, while the duration of the target tone was different for each task. The longer the target duration, of course, the more difficult the task. According to our hypothesis, blink latency to a <u>nontarget</u> stimulus should be a function of the duration of the <u>target</u> stimulus with which that nontarget stimulus is paired on a given task. It should be reemphasized that the nontarget stimulus is the same for all tasks and thus the critical comparison will be of blink latency to the same stimulus.

Methods

Subjects. Eight Washington University undergraduates served as subjects for this experiment.

Apparatus. The apparatus was the same as that described in Experiment 1.

Procedure. Subjects participated in four duration discrimination tasks of 5 minutes each. The order of presentation of the tasks was counterbalanced.

The nontarget duration for all four tasks was constant at 500 ms. The target durations for the four tasks were 120, 220, 320, and 420 ms, respectively. The subjects, as in experiment 1, were instructed to respond to the short-duration tone only. Ninety-three stimuli were presented at 3-second interstimulus intervals; the ratio of target to nontarget tones again was 1:2. A 20-trial practice session preceded each task, as in experiment 1. Subjects were tested on all four tasks in a single session taking approximately 1 hour.

Data reduction and analysis. The data were recorded on magnetic tape, and digitized off-line and reduced using the same procedures as in experiment 1. All data were subjected to ANOVA.

Results

Performance Measures.

Performance measures confirmed that the difficulty manipulation was successful. As target duration increased, Hit rate decreased ($p < .01$) and False Alarm rate increased ($p < .05$). As can be seen in Figure 4, reaction time (bottom tracing) increased with target duration, but the increase was not significant ($p = .06$).

Physiological Measures.

Blink latency. In Figure 4 are also plotted blink latency following both target and nontarget trials. With respect to nontarget stimuli, blink latencies were measured from stimulus onset since, according to the hypothesis, the information necessary for the discrimination is available during the nontarget stimulus, i.e., at the point during the nontarget stimulus when the target duration is exceeded. Blink latency, accordingly, increased significantly ($p < .01$) with target duration, as predicted.

To assess the linearity of the relationship between target duration and blink latency, a correlation coefficient was calculated for these variables; $r = 0.98$, explaining 97.6% of the variance. In addition, the slope of the regression line relating these variables was 1.18, indicating a 118-ms increase in blink latency for each 100-ms increment in target duration, almost a perfect relationship.

Target blink latency, unlike nontarget latency, was measured from stimulus offset, since not until the target stimulus terminated could the discrimination process begin. Here, too, latency increased with target duration ($p < .01$). The correlation between target duration and blink latency was 0.71, which explained about half the variance, and the

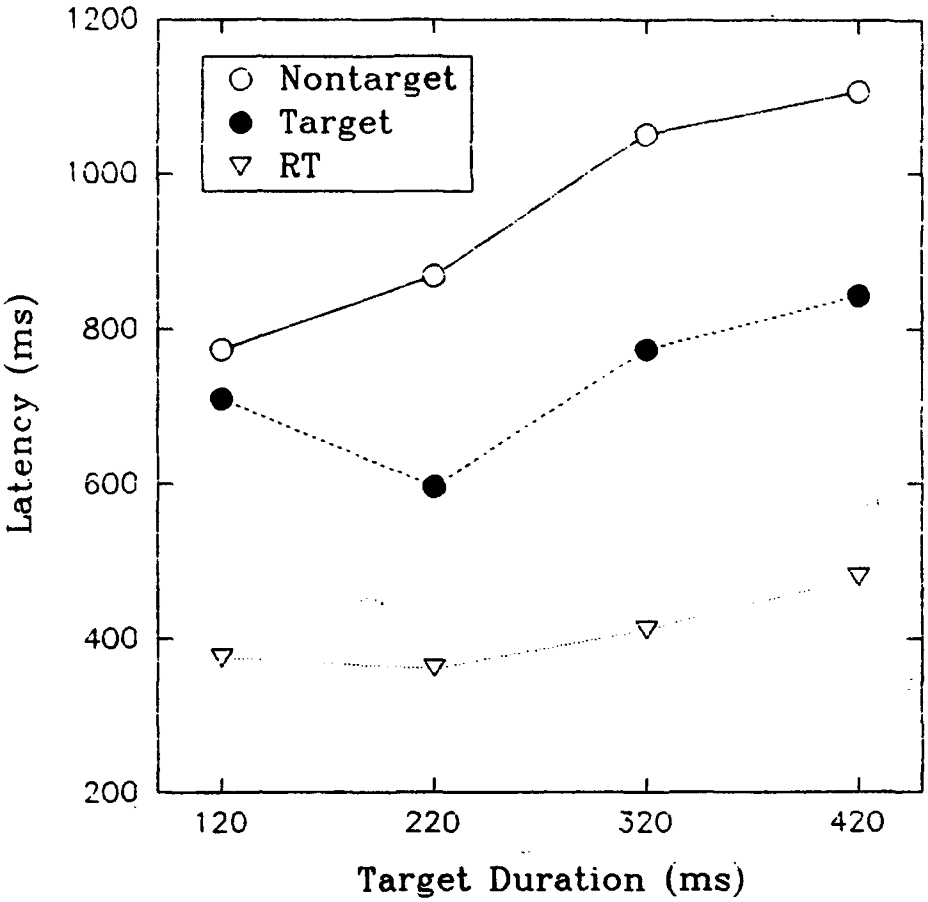

Figure 4. Experiment 2 – Blink latency and reaction time as a function of target duration.

slope was 0.58, indicating that the increment to blink latency is not a 1:1 function of the increment added to target duration.

Discussion

These results, along with those of experiment 1, support the position that processing time, and, perhaps to a lesser extent, difficulty, is a major determinant of blink latency. Normally, these two factors are confounded, more difficult judgments requiring more time. But this is not always the case, as is evidenced here. The fact that increments to target duration were matched almost exactly by increments to nontarget blink latency is a powerful confirmation of the decision time hypothesis. That the slope was slightly above 1.0 could be due to the fact that as target duration increased, the nontarget duration necessary to detect the increment increased proportionately, as psychophysical principles would dictate, rather than linearly. This proportionate measure would be consistent with a difficulty interpretation. In any event, these findings demonstrate the potential utility of blink timing as an index of the onset and termination of decision processes and, most significantly, in the absence of a manual response.

The increase in blink latency following target stimuli presents a problem. Since latency was measured from stimulus offset, an increase in target blink latency is more supportive of a difficulty interpretation than a time interpretation. While a difficulty factor is possible, even the most difficult task was at least as easy as the easiest task in the first experiment where very few errors were made. Suggestive of an alternative explanation was the relationship between RT and target blink latency. Target blink latency decreased more than 100 ms when target duration increased from 120 to 220 ms, and then increased thereafter. This pattern bears a subtle resemblance to that exhibited by manual reaction times. This parallel is relevant in that the manual response obviously is made on target trials, the same trials on which target blinks are made, and prior work clearly demonstrates that blinks tend to be deferred until after the execution of the manual response. It is suggested that on target trials, the blink is affected by some factor that affects the occurrence of the manual response.

A candidate for this factor is the foreperiod effect. Accordingly, the onset of the target stimulus is serving functionally as the warning stimulus and the offset of the target stimulus serves as the imperative stimulus in a choice reaction time experiment. Since reaction time and blink latency were at their lowest at 220 ms, the present data would then suggest that 220 ms may be the optimal warning duration under the conditions of these tasks. These speculations, of course, are tentative, but there are data

in the literature pointing to the foreperiod as a significant factor in determining reaction time (e.g., Näätänen and Merisalo, 1977). This corollary could be tested by omitting the nontarget stimuli, making it a simple reaction time task. If the foreperiod interpretation is correct, both the significant target stimulus duration effect and the inversion will still be present, although the inversion might occur at a lower point since the inhibiting effect of the nontarget stimulus would be removed. An alternative test would be simply to increase the duration of the nontarget stimulus to a value in the 1 or 2-sec range, which would circumvent the latter problem by maintaining the complex reaction time character of the task. At the same time it would make all tasks that much easier and, if difficulty were the critical variable, would reduce or eliminate the target duration effect.

EXPERIMENT 3

In several studies in this laboratory (Bauer, Strock, Goldstein, Stern & Walrath, 1985; Goldstein, Walrath, Stern & Strock, 1985) it was found that over trials, RT increased, as would be expected, or remained the same, while blink latency decreased. Blink latency showed the usual decrease over trials in experiment 1, and while the RT increase was not significant ($p = .08$), it did increase. The blink latency decrease was substantial for the Hit trials and only slightly less so for the correct nonresponse (CNR) trials, an effect seen in earlier studies. The hypotheses that RT and blink latency are both associated with the decision process, and that the programming and execution of the manual response simply represent an additional cognitive process that further defers the blink, seem wanting in light of the different RT and blink latency time-on-task patterns. Adding to this problem is the fact that in previous studies (exemplified by Goldstein, Walrath, Stern & Strock, 1985), although not in experiment 1 of this series, blink latency for CNR trials did not decline over trials at all. This tendency reinforced the notion that the blink latency decline was related to the manual response. Assuming that the source of the RT effect over trials is ascribable to fatigue and/or to a developing attentional deficit, the problem addressed here is identification of the source of the blink latency decline and the differentiation between it and the factors controlling the RT change over time.

The possibility entertained here is that there are several processes at work. We continue to adhere to the hypothesis that blink latency is, in some respects, slave to the occurrence of the manual response, which accounts for the consistently demonstrated fact that blink latency is greater following response than nonresponse trials. Thus, fatigue and attentional factors would affect both RT and blink latency. But in addition to this factor, the fact that

blink latency can decline over trials in the absence of a manual response suggests that some factor prior to those associated with the response is "improving" over trials. It is to this process that the blink latency is particularly responsive. The hypothesis, at present, is that this process is that of invocation of the rule that guides the subject's response (viz., the rule that is conveyed in the instructions given to the subject) that is improving over trials. Further, the fact that in some studies the CNR trials fail to show the blink latency decline is attributable to the fact that on CNR trials, blink latency is typically quite low at the outset of the experiment, limiting the degree to which it may drop further over trials.

If blinks are affected by events in the cognitive chain that are earlier than the programming of the manual response, it would then be the case that early factors would affect both RT and blink latency while late factors, such as fatigue, could affect RT only. There are further assumptions that would be necessary in order to flesh out this model, which will await the outcome of this study. At present, an attempt will be made to separate the contributions of the various processes discussed and to assess the role of each in the change in blink latency over trials.

In this task, following presentation of the discriminative stimulus, there are at least four processes contributing to blink latency that may be identified. First, the subject must make a decision (D) as to the duration of the stimulus. Second, the rule must be invoked that applies to the situation. In the case of the previous study, for example, it was: "If the stimulus is short, respond; if not, inhibit responding." This process is designated, "Rule Invocation" (RI). Included in this process is the evaluation of the stimulus against the conditions set forth in the rule.

If a response is called for, a motor response may be prepared; this is designated "Motor Programming" (MP) and is the process whereby the set of motor commands required for a particular response is assembled. Motor programming can only take place when the subject knows that a response is to be made and what the response is to be. When a response is unnecessary, or when the nature of the response cannot be predicted, no motor programming occurs. The final process is "Response Execution" (RE) which is the running off of the programmed motor response.

There will be three conditions in this experiment. In all three, the same discrimination tones will be used. The conditions will be differentiated only by the instructions, which are designed to manipulate the three processes described above.

Methods

Subjects. Subjects were 42 Washington University undergraduate students, 14 in each group.

Apparatus. The stimuli to be discriminated (200- and 400-ms tones) were presented through a speaker located directly in front of the subject, as in experiments 1 and 2. In addition, there were two other speakers on the table at which the subject was seated. These were located on the table in front of, and to either side, of the subject. Stimuli presented through the side speakers were tone blips, 50 ms in duration and at one of two pitches. The pitches of the tone blips and center tone were all clearly distinguishable from each other.

Procedures. In all three conditions there were two stimuli per trial. The first stimulus (stimulus "A") was either a 200- or a 400-ms tone. The second stimulus (stimulus "B") was always the 50-ms tone blip. Interstimulus intervals between A and B, and between B and the next A, were 6 sec. The session started with a 20-trial practice series, followed, after a brief period for changing the program, by 201 regular trials.

The basic task for the subject, as in experiments 1 and 2, was to discriminate the durations of the two tones in the "A" position. The response consisted of lifting a finger from a contact pad and then replacing it. Half the subjects in each of the first two conditions responded with their left hands and half with their right. The response contingencies for the third condition is described below. The following description may be clarified by referring to Figure 5 (in following text). Arrows indicate the response requirement.

Condition 1 - The 200-ms tone is the target stimulus. If stimulus A is short, the subject's task is to make a motor response immediately following the discriminative decision. If stimulus A is long, no response is made. To stimulus B, the subject will make the motor response, as a simple reaction time response, regardless of the duration of stimulus A. Although stimulus B will be either high or low pitched and will be presented on both the left and right, the subject will be instructed to disregard these variations.

Condition 2 - The 200-ms short tone is the target stimulus. Here, however, the subject is instructed not to respond at stimulus A. At stimulus B a response is required only if stimulus A is short. Once again the subject's task is to ignore the pitch and location of stimulus B.

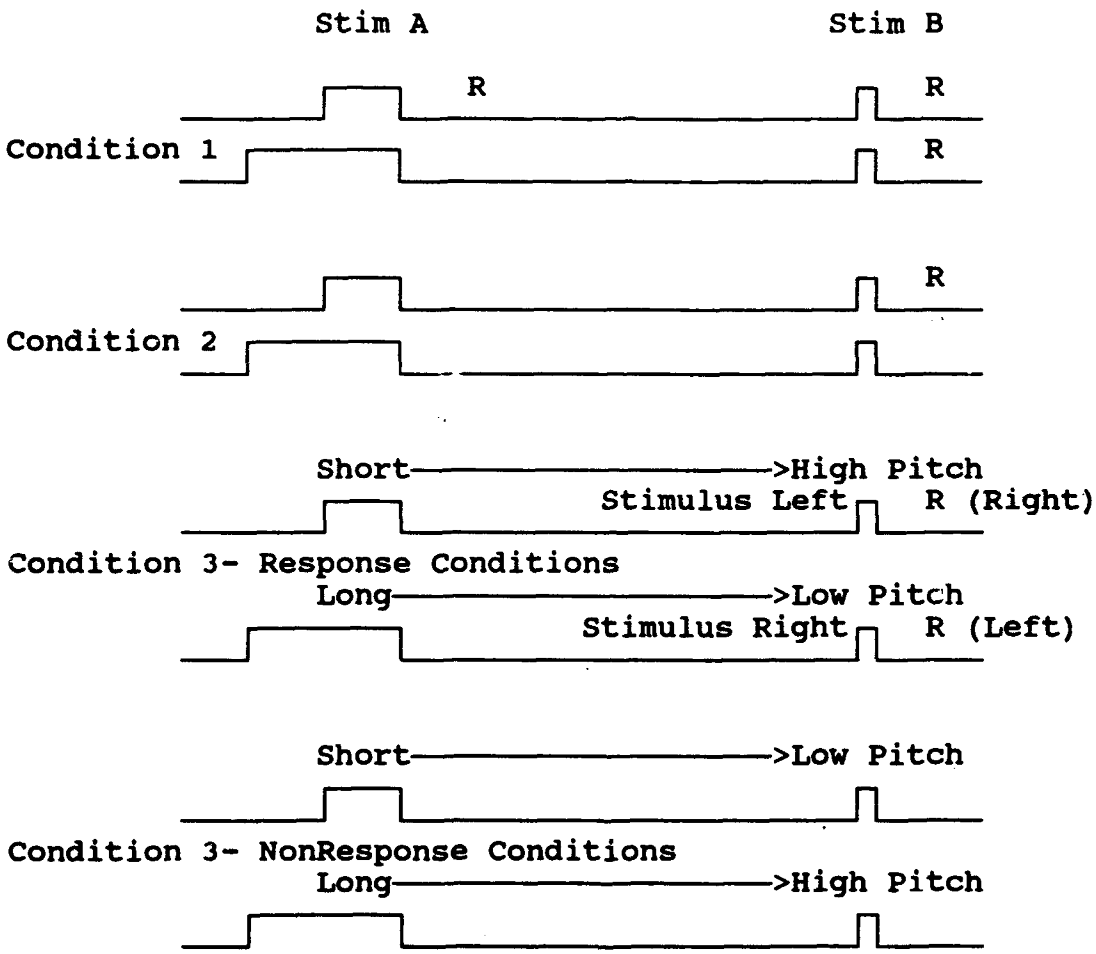

Figure 5. Experiment 3 - Schematic of the three conditions. "R" represents a manual response.

Condition 3 - In this condition, either tone at stimulus A may be the target tone. In either case, the subject is not to respond at stimulus A, but delay responding till stimulus B. Which stimulus he is to respond to and with which hand he is to respond at stimulus B depends on the information conveyed by the pitch and location of stimulus B. There are two conditions under which the subject is to respond:

1. Stimulus A is short AND stimulus B is high pitched, or
2. Stimulus A is long AND stimulus B is low pitched.

When either of these criteria is met, the location of stimulus B determines the hand with which the response is to be made. The right speaker indicates the left hand and the left speaker, the right hand. In condition 3, therefore, either the short or long stimulus can be the target stimulus. For the other two combinations (viz., short-low and long-high), the subject is not to respond.

Predictions and Rationales.

Condition 1 - Following a short stimulus A, according to our analysis, the subject must utilize all four processes (D-RI-MP-RE), as in previous studies. On long "A" trials, D and RI are necessary following "A". Following presentation of "A", the subject is actively programming a simple RT motor response to be executed upon the detection of stimulus B. Therefore upon presentation of "B", the subject must go through only a single process, viz., response execution (RE).

Condition 2 - Following a short stimulus A, three of the four processes may occur. D occurs immediately; RI ("Respond at next tone") and MP would occur later in the interval. At stimulus B, the subject must execute the motor response (ME).

Following a long A, the subject will utilize D. Again RI might occur later in the interval to the effect that the subject is to ignore the next stimulus.

Condition 3 - Following stimulus "A", we assume that only D, and perhaps, later, RI will be used. No motor programming will occur during this interval since the nature of the response (or even whether a response will be required) cannot be known until stimulus B is presented. Emphasizing this assumption is the fact that the ratio of response to nonresponse trials is 1:2, which creates a negative response bias. Following stimulus B, the subject will need to apply the rule (RI) to determine whether a response is necessary. If it is, MP and RE will ensue.

The working hypothesis is that the decrement over trial is due to increase in the efficiency of the RI process. But only when the baseline is elevated (either by the occurrence of a motor response as, for example, in condition 1B, or by increasing the time necessary to complete the task, as in 3B) will it be possible for the truncation of the process over trials to be manifested in blink latency. Since in 1B there is minimal, or no, D or RI component, the prediction is that there will be no decrement. On the other hand, there will be a decrement in 3B since there is a substantial RI component prior to the response, and since baseline will be elevated by the prolonged RI, the decline in blink latency over trials will be apparent.

Following along these lines, predictions for the other conditions are as follows:

1. 1A: this is essentially a replication of previous experiments. Prediction: a reduction in blink latency for Hit trials will be observed but less so, or not at all, for CNR trials and therefore an interaction of time by response type.

2. 1B as explained above: no decrement with trials.

3. 2A: there is no baseline elevation and therefore the RI reduction will be minimal or absent for both target and nontarget trials.

4. 2B: For target trials, latency is elevated by association with the motor response. But since there is little D or RI, there will be no decrement. For nontarget trials, there is no response, and therefore, no baseline elevation; accordingly, no decrement is predicted.

5. 3A: As in 2A, there is no elevation and consequently no decrement is predicted.

6. 3B: As explained earlier, a substantial decrement is predicted in both Hits and CNRs.

Data Sampling.

In order to accumulate a sufficient number of blinks for each factor, especially in condition 3, where there were many factors, it was unfortunately not possible to use 5-minute sampling periods as in experiment 1. A second design constraint was the session duration which had to be reasonable, yet allow the time-on-task effect to be manifest. The result of these considerations was that the session was 40 minutes long (as in experiment 1) and two 15-minute samples were taken; the first sample was the initial 15 minutes of the session and the second, the final 15 minutes of the session.

Results

Performance Measures.

Hit Rate and False Alarm Rate. Hit rates and False Alarm rates are presented in Table 6. These data were arcsine transformed and subjected to ANOVA. Results indicated that Condition had a significant effect on Hit Rate ($p < .01$); hit rate in condition 3 was less than in conditions 1 or 2. False alarm rate was also affected by condition ($p < .01$) and again, condition 3 showed more false alarms than either of the other two conditions. Thus, the assumption that the tasks differed in difficulty appears to have been validated.

Table 6. Hit Rate and False Alarm Rate in all conditions (Experiment 3).

	Condition					
	1		2		3	
Time	Ear	Lat	Ear	Lat	Ear	Lat
Hit Rate	.97	.99	1.0	.98	.96	.93
FA Rate	.03	.04	.01	.01	.06	.06

Reaction Time RT. Reaction times for all conditions for which a response was required (1A, 1B, 2B and 3B) are presented in Figure 6. Since the predictions were essentially for individual stimuli within conditions, separate ANOVAs were done for each. In no case, except 1B, was the time effect significant. For 1A, 1B, 2B and 3B, p-values for the time effects, were: .97, .05, .34 and .27, respectively. For condition 1B, RT increased over time. Another analysis was performed comparing RT responses that were relevant to the discrimination, viz., 1A, 2B and 3B. The only significant effect was the condition effect ($p <.001$). As can be seen in Figure 6, this significance is due to the long RT in condition 3B.

Physiological Measures.

Blink Latency. Several passes of the blink latency data were made. Since the predictions were essentially within condition, the analyses followed this approach, so that six ANOVAs were carried out, two for each condition, one for the "A" stimulus and one for the "B" stimulus.

The first series of analyses was on the latency of the first blink in the 6-sec ISI. As can be seen in the top block of Table block "6K", the results of this analysis

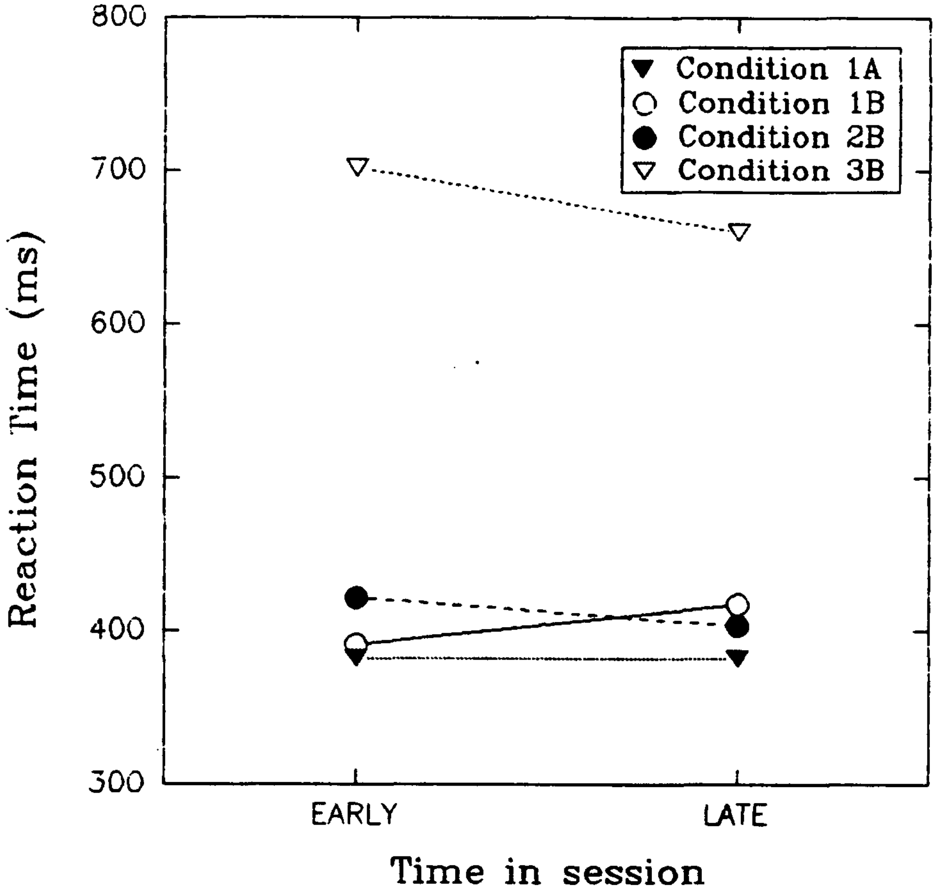

Figure 6. Experiment 3 – Reaction time in all response conditions: 1A, 1B, 2B and 3B.

were, in very few instances, supportive of the predictions. This poor agreement might have been due to the unrestricted inclusion of any blink, regardless of its latency, as long as it was the first poststimulus blink, which could include blink latencies up to 6 sec. But a cognitive process evoked by a stimulus may, in many instances, be quite transient. If so, inclusion of blinks beyond the period where that processing occurs would not differentiate two experimental conditions that differ in terms of use of that process. Accordingly, a second pass of the data was made excluding blinks with latencies beyond 3,000 ms and finally, following the same approach, a third pass was made restricted to blinks with latencies under 2,000 ms.

For summary purposes, the p-values associated with all effects, and for all three passes, are tabulated in Table 7. Asterisks are placed next to significant values. The data in this table are organized by cutoff rather than by condition as they are in the subsequent figures.

Table 7. Probability values from ANOVA F-tests of blink latency, as a function of stimulus type (HIT/CNR) and time, for Stimulus A and Stimulus B for each condition (Experiment 3).

		Stimulus A			Stimulus B		
		TIME	STIM	TXS	TIME	STIM	TXS
6K	Cond. 1	.165	.132	.303	.329	.019*	.018*
	Cond. 2	.578	.626	.202	.691	.742	.943
	Cond. 3	.505	.021*	.098	.158	.007*	.226
3K	Cond. 1	.269	.0005*	.022*	.139	.018*	.054
	Cond. 2	.566	.301	.163	.735	.141	.986
	Cond. 3	.218	.002*	.769	.043*	.021*	.863
2K	Cond. 1	.119	.0007*	.033*	.017*	.082	.03*
	Cond. 2	.607	.034*	.032*	.609	.025*	.627
	Cond. 3	.412	.0005*	.439	.108	.441	.512

The means of the effects to which these analyses refer are presented graphically in Figures 7, 8, and 9. Probability values for significant effects (with one exception) are presented on each panel. The p-value for the time effect is located between the baseline tick marks for the Early and Late conditions. The p-value for the stimulus type effect is placed between the graphed Hit and CNR functions and the interaction p-value, TXS, is above the two functions of each panel. The designations, "HITs" and "CNRs", are used for the stimulus type variable. In 1B, 2A, and 3A, there are no discriminative response requirements, so that these labels

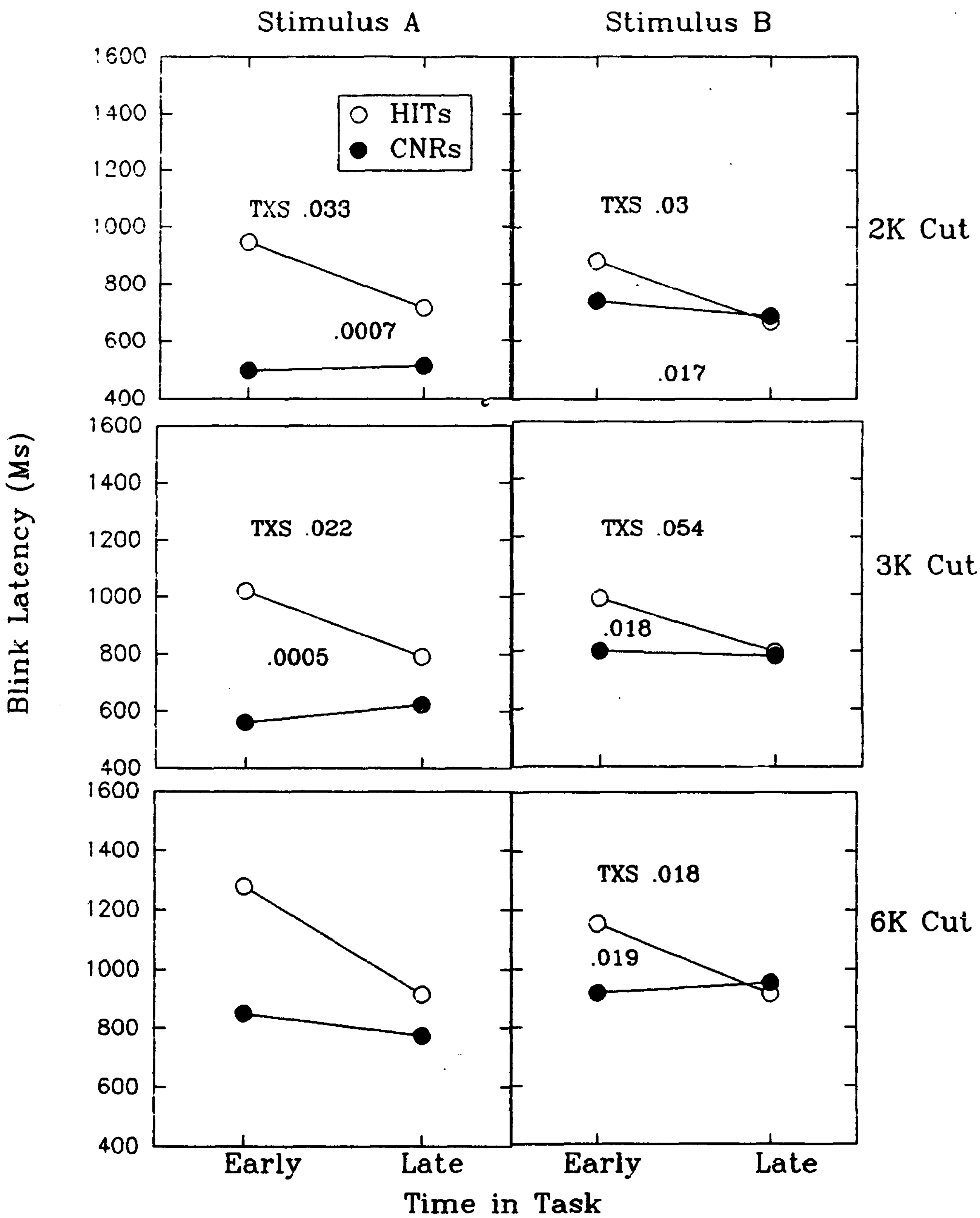

Figure 7. Experiment 3 – Conditions 1 A and 1B for three maximum blink latency criteria. The designation, "2K Cut," indicates that no blink with a latency greater than 2,000 ms was included.

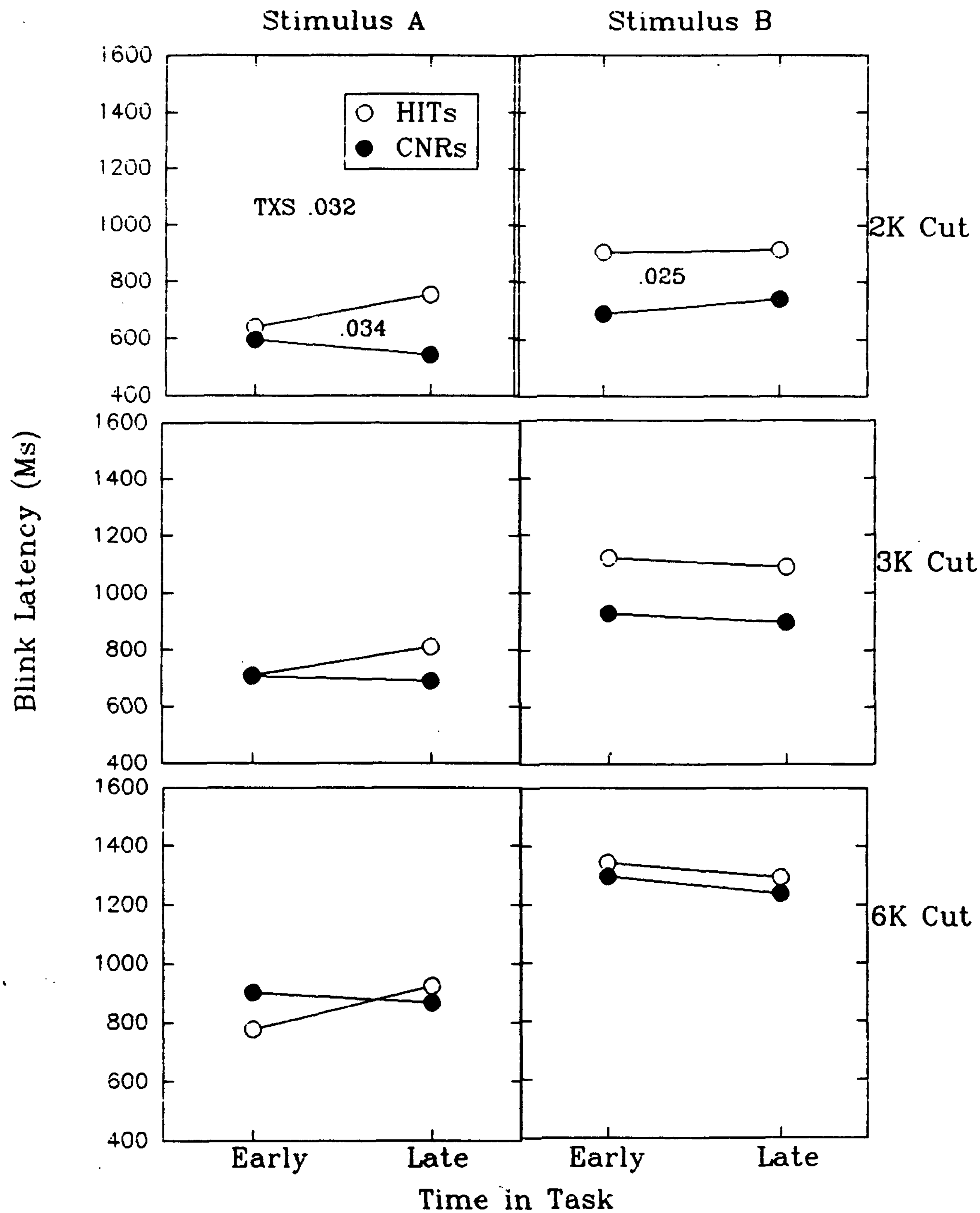

Figure 8. Experiment 3 – Conditions 2A and 2B for three maximum blink latency criteria. The designation, "2K Cut", indicates that no blink with a latency greater than 2000 ms was included.

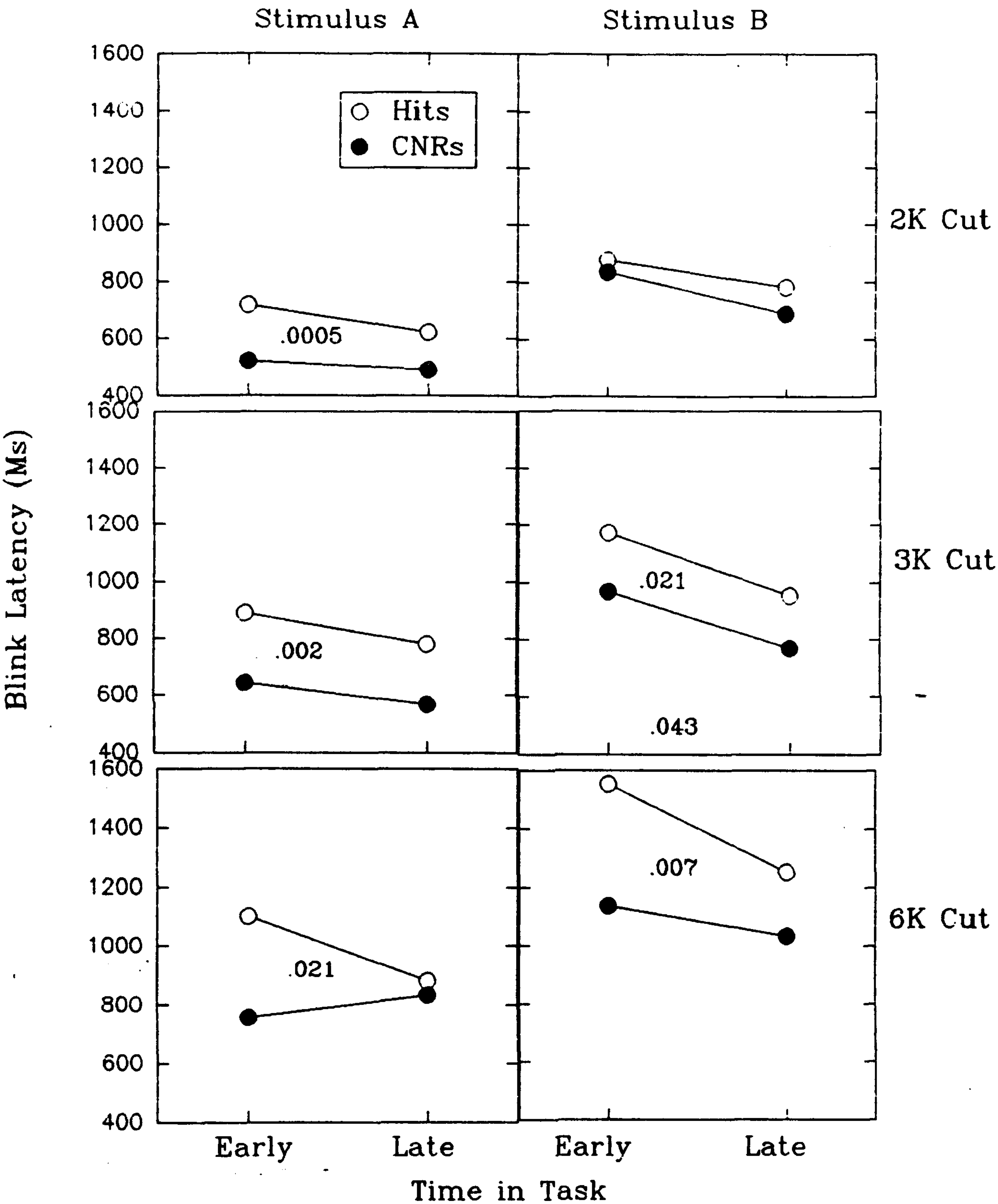

Figure 9. Experiment 3 – Conditions 3A and 3B for three maximum blink latency criteria. The designation, "2K Cut", indicates that blinks with latencies greater than 2000 ms were omitted.

are merely nominal, related only to the response requirement earlier (in the case of 1B) or later (for 2A and 3A) in that trial.

Turning to condition 1A (discriminative response required) in Figure 7, we see that even though the means are organized as predicted, the interaction referred to above for the 6K cut, is not significant. Although the relationship among the means remained constant as the cutoff was moved in, the stimulus type and the TXS interactions were now significant for both the 3K and 2K cutoffs. This significance must be attributed, then, to a reduction in variability effected by excluding late blinks irrelevant to the independent variables.

In 1B (simple RT response required), the results were mixed. In two of the three cuts, stimulus type was significant, contrary to prediction. More important, in two of the three cutoffs, the interaction was significant and in the third, the 3K cut, the p-value was .054. No interaction was predicted. In one instance, the 2K cutoff, the time effect was significant, clearly attributable to the decline in the Hit function.

In condition 2A (no response required), not until the cutoff was restricted to 2K did any effects become significant, as can be seen in Figure 8. Following stimulus A, there emerged a significant stimulus type effect and an interaction, but no time effect. Although the stimulus type effect and the interaction were not predicted, the absence of a time effect was. Note, in this regard, that the Early "HIT" level was low, as predicted to occur in the absence of a manual response or any prolonged preresponse process. With respect to condition 2B (simple RT only after a short stimulus A), there were no interactions. The pattern in the 3K and 2K analyses were as expected, the Hit condition exceeding the CNR condition in the 2K analysis. And there was no sign, using any cut criterion, of a time effect even though baselines were higher in 2B than in 2A.

In condition 3A (no response required), even though baselines were low initially (see Figure 9), there was a significant stimulus type effect, which grew clearer as the cutoff became more restrictive. This effect occurred in spite of the fact that there was no response necessary to stimulus A, and, moreover, there was no preparation possible that differentiated the short and long stimuli.

Whereas in the above conditions, the consequence of making the criterion more restrictive was that when it had an effect, it increased the strength of the effect; in 3B, this tendency was reversed. As the cut was reduced, the effects became weaker and finally, at the 2K cut, there were no significant effects. The effect at the 3K level was as

predicted; both baselines were high, with the response condition higher than the nonresponse condition, and both declined with time. Although at the 6K cut there was no time effect, the stimulus type effect was present, and in no cut was the interaction significant.

In order to gain some additional perspective as to the basis of these changes, the distributions of blink latencies throughout the intertrial interval following Hit and CNR trials were plotted. Latencies (and note that these are the first blinks following stimuli) were grouped into 300 ms bins but only for those subconditions where the change in the cutoff criterion changed the outcome markedly, viz., in conditions 1A 1B, 3A and 3B. In Figures 10 - 13, respectively, are graphs of the results of these analyses.

In relating the material in Figures 10 - 13 to Figures 7, 8 and 9, it should be kept in mind that Figures 10 to 13 contain a bin-by- bin (each bin 300 ms) breakdown of all first-blinks that occurred in the interstimulus interval, whereas Figures 7, 8 and 9 contain the average of all first-blinks that occurred in the specified interval.

Several aspects are clear in examining these figures. In almost all cases, the blinks occurring after 3 sec appear to be irrelevant to stimulus type or time. The single exception to this generalization is condition 3B, displayed in Figures 9 (right side) and 13. In Figure 9, the p-value for the stimulus type effect (HITs vs. CNRs) is significant at the 6K cut but increases as longer latency blinks are excluded. Finally, at the 2K cut stimulus type is no longer significant. The time effect is present only at the 3K cut. Relating this trend to Figure 13, we note that in Figure 13, latencies in the first bin do not discriminate early from late nor stimulus type. It is not until bin 2 that the blink latencies for the different conditions diverge. This tendency is consistent with the RT data, where latency in the 3B condition was more than 250 ms longer than in the closest of the other conditions.

As will be recalled from experiment 1, differences in stimulus type were attributable to the point of origin of the blink latency measure. That is, blink latencies were measured from stimulus offset, which, it will be recalled, introduced a negative "artifact" into the CNR latency. When that latency was adjusted there, the stimulus type differences were severely attenuated. The same correction was made here, adding target duration to CNR blink latencies for all "A" conditions. When the adjusted "A" data were reanalyzed, all stimulus type effects, as expected, disappeared, with the single exception of condition 2A, for the 3K cut, where a significant stimulus type effect now appeared where it didn't exist before.

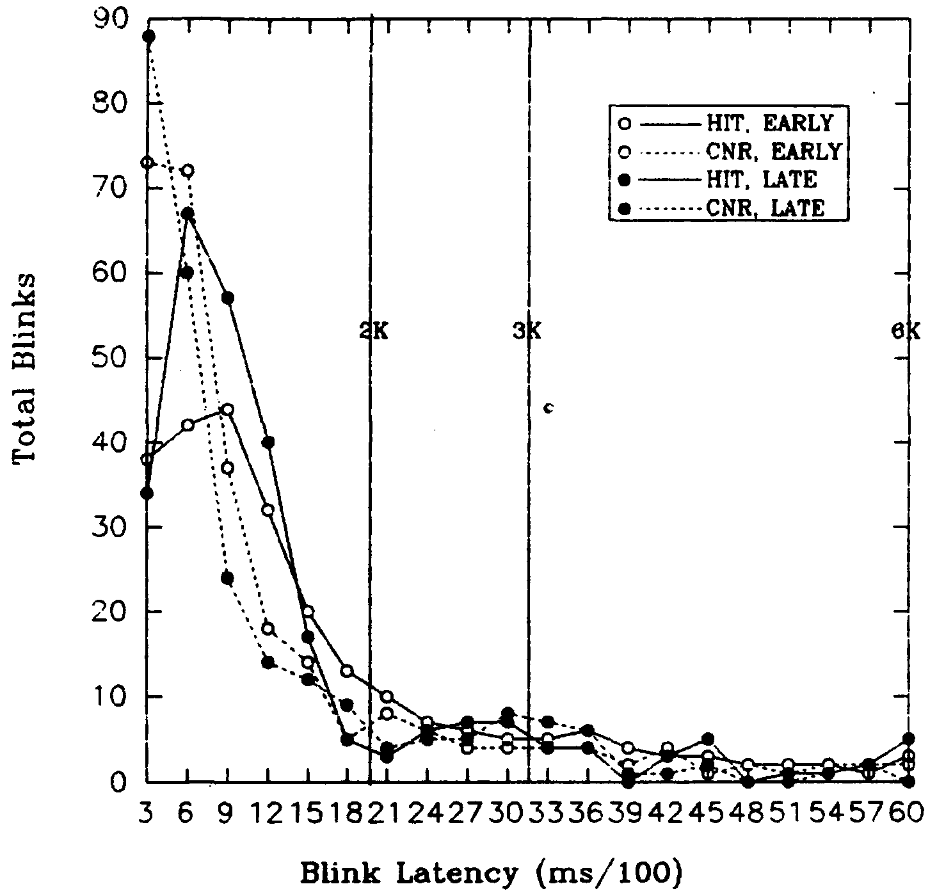

Figure 10. Experiment 3 – Condition 1A. Blink latency in 300-ms bins following HIT and CNR trials, as a function of time on task. Ordinate is total blinks for all 14 subjects.

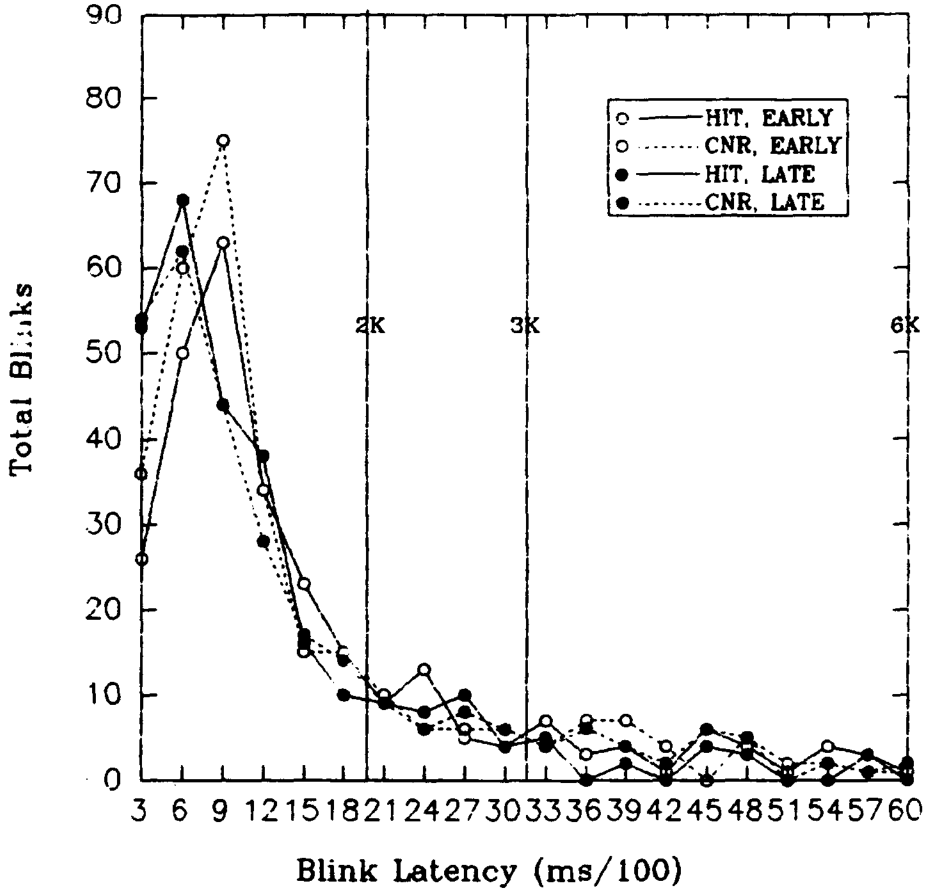

Figure 11. Experiment 3 – Condition 1B. Blink latency in 300–ms bins following HIT and CNR trials, as a function of time on task. Ordinate is total blinks for all 14 subjects.

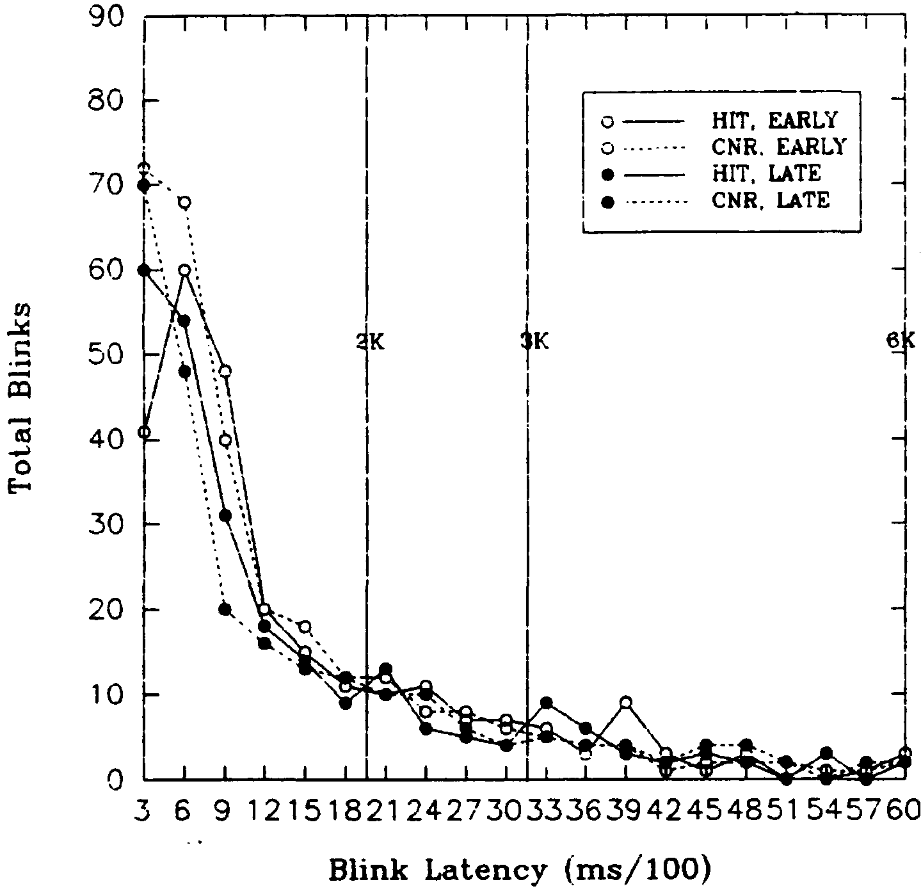

Figure 12. Experiment 3 – Condition 3A. Blink latency in 300–ms bins following HIT and CNR trials, as a function of time on task. Ordinate is total blinks for all 14 subjects.

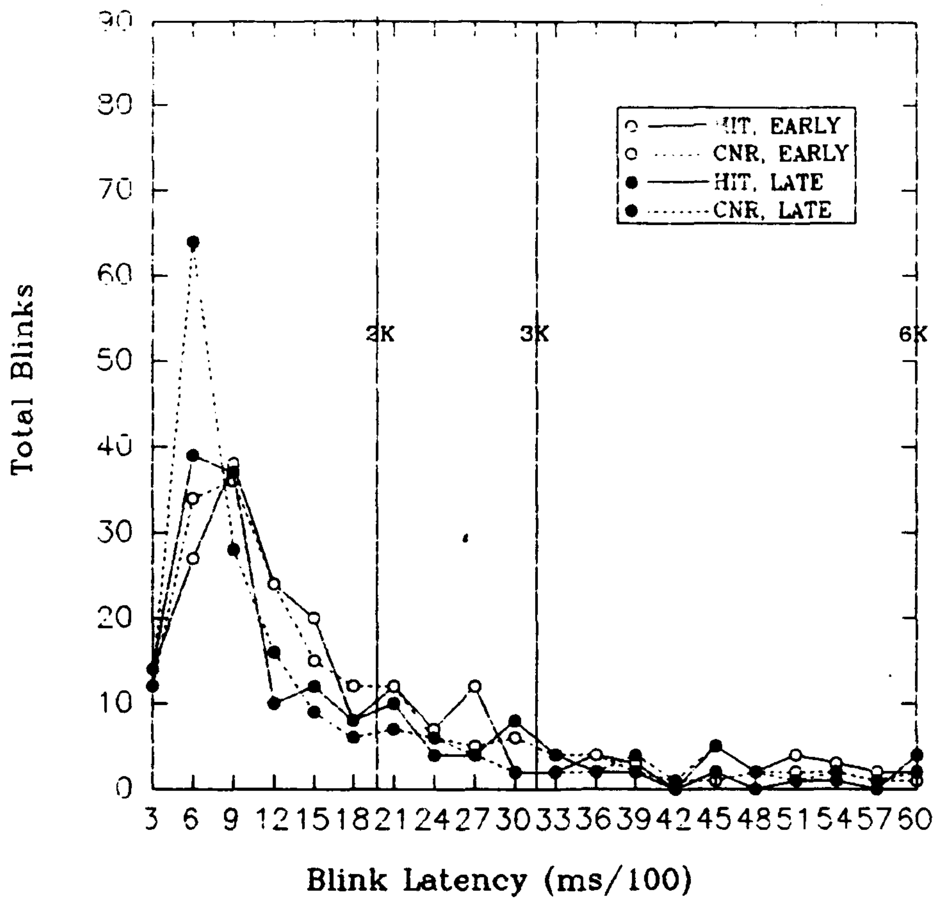

Figure 13. Experiment 3 – Condition 3B. Blink latency in 300–ms bins following HIT and CNR trials, as a function of time on task. Ordinate is total blinks for all 14 subjects.

Discussion

With respect to the stimulus type (HITS vs. CNRs) effects in the "A" conditions, the results once again confirm the basic hypothesis. That is, when the measurement of nontarget blink latency is taken from the point where target duration ended, then, with only one exception, the stimulus type effect was absent. The same effect was noted in Experiment 1.

This adjustment to nontarget blink latency is based on the assumption that the occurrence of a blink awaits the decision as to whether the stimulus is the target or nontarget stimulus. For the 400-ms nontarget stimulus, this determination can be made during the stimulus, soon after the target duration (200 ms) elapses. Thus, when latency is taken from this end point, rather than from stimulus offset, and the result is to delete the stimulus type effect, it confirms the importance of the cognitive decision process as a controlling factor in blink latency.

The results of the variable cutoff analyses, while clarifying in some respects, are problematic in other respects. It seemed clear, for example, that in condition 3B, which was designed to increase decision latency, blink latencies would also be expected to increase. In searching for the effects of experimental conditions in situations such as this, therefore, it would be appropriate to focus on a later poststimulus period than in other conditions where the effects of experimental conditions might be expected to occur earlier. Consistent with this hypothesis, the stimulus type effect was seen most clearly at the 6K cut and declined with subsequent cuts until at the 2K cut, the stimulus type effect disappeared. This trend is taken to mean that the stimulus type effect is a late effect which will be manifest only if the cutoff allows late events to be included.

The time effect for 3B, on the other hand, was significant only at the 3K cut. We interpret this result to mean that the process develops after 2 sec and is completed before 6 sec.

These conclusions should be qualified to recognize the fact that in every case, the analyses are cumulative. A late process, for example, in order to be manifest, must overcome the masking effect of earlier irrelevant events. It may be the case, then, that the maximal effect occurs prior to 6K but it requires the addition of subsequent, but less than maximal, effects to counter the masking effect of early noise.

The problematic aspect of this analysis is its *ad hoc* character. A troubling question is which of the three analyses should be taken as representing the true state of

affairs. An apparent solution would be a bin-by-bin analysis, rather than the more gross analysis of means. The number of blinks per bin/subject, however, is not sufficiently large to support this approach. Pooling bins might be helpful although the more bins pooled the more gross the analysis. This is not a question that will be resolved in this report. The approach taken here will be to attempt to fairly characterize the general trends in the data.

We shall now turn to the interpretation of the blink latency data with respect to the hypotheses presented on pages 18 and 19. First, in condition 1, we see in Figure 7, stimulus A, the familiar pattern of a declining HIT latency over time in conjunction with a stable CNR latency. The constant CNR level, it will be recalled, was attributed to the relatively low baseline latency level, which seems to be the case. This rationale contrasts with 3B, discussed above. In 3B, CNR, as well as HIT, baselines were elevated by the difficulty of the task and consequently, blink latency declined with time for both HIT and CNR conditions despite the fact that in the HIT case, a response was made and in the CNR case, there was no response. These effects, taken together, are consistent with the position that the decrement is due to an increase in the efficiency of the rule invocation (RI) process rather than with responding.

Condition 2B is a situation where the decision had been made earlier, and a simple RT response is executed. These data are presented in Figure 8. In neither the HIT nor the CNR cases was a discrimination decision necessary and in the HIT case, a response was executed. Here, there was no change in blink latency over time and no interaction: these effects would be predicted from an RI hypothesis. The effect of the response to the HIT stimulus (and note that in 2B, both "HIT" and "CNR" stimuli are the same 50 ms) is simply to elevate latency.

The results from 1B are difficult to interpret in either an RI or a response context. Here, the task was a simple RT to both B stimuli. The responses were completely independent of the A discrimination, and yet there was an interaction that was due to a decline in the "HIT" function over time in the face of a constant "CNR" latency. The HIT decline was sufficient, in fact, to produce a significant time effect.

In 2A and 3A, a discrimination was made but no responses were called for. In the absence of delaying factors, baselines were relatively low. As hypothesized, these are not optimal conditions for the manifestation of the posited decline due to the RI process, and thus no decrements were predicted, and none were seen. No attempt will be made to interpret the anomalous interaction in 2A (2K) nor the 2A

(3K) appearance of a stimulus type effect when means were adjusted.

One problem with the present design, mentioned earlier in this report, is that the duration of the sampled periods might have militated against finding time effects. That is, the activity in the first 15 minutes of the session was compared to the activity in the final 15 minutes of the session with only a 10-minute period intervening between these samples. This protocol was chosen to insure a sufficiently large sample of blinks, particularly in condition 3, where there were several subvariables, e.g., right hand - left hand, short A/high B - long A/low B. In retrospect, since the data were pooled over these variables, the time samples could have been smaller and, consequently, more separated in time.

Nevertheless, in general, the results of experiment 3 provide reasonable support for the hypothesis that processes prior to those related to response programming and execution are the basis of the decline in blink latency over time. When baselines are sufficiently high, and whether responses are called for or not, there is a decline with time. What happens when there is no strong RI component, and when there is a response required is less clear. The data for condition 2B suggests that the occurrence of a response is not pertinent to the decline even when baselines are relatively high.

EXPERIMENT 4

The following study was an exploration of the factors that control saccades and head movements to peripheral targets.

It has been established that saccade latencies to targets within 20 degrees of a central fixation point are not significantly different from one another. Saccades to more eccentric targets, however, are delayed as eccentricity increases. For example, in requiring subjects to fixate lights presented at various eccentricities, White, Eason, & Bartlett (1962), and Bartz (1962), demonstrated that saccade onset to the target was an increasing function of eccentricity. These authors also demonstrated that factors other than target eccentricity affect saccade latencies. For example, saccade onset to a target whose location is unpredictable is delayed relative to a predictable target (Findlay, 1981). Further, Abrams & Jonides (1988) showed that saccade latencies are affected by advance knowledge of the direction and distance necessary to fixate the target (a "to-target" saccade).

Finally, the time between a warning signal and target presentation also has been shown to affect saccade laten-

cies. If termination of a warning signal and onset of a peripheral target are simultaneous, saccade latencies to the target are about 200 ms. As the delay increases, however, latencies decrease, but if termination precedes the onset of the target by 100 ms or more, latencies increase again (Saslow, 1967). Additionally, Houtmans & Sanders (1984) have shown that targets appearing within 30° - 40° of central fixation require only movement of the eye to achieve target acquisition (defining the "eye field") while those occurring outside the 40 degree range also require a head movement (the so-called "head field").

Factors that affect head movements can be categorized into those that affect acquisition of a target and those that involve processing of a target. Factors known to affect the amplitude and likelihood of head movements during target acquisition are, target clarity (Houtmans & Sanders, 1984), target modality (Siegmund, Stoppa, & Santibañez-H, 1987), complexity of the display (Robinson, Koth, & Ringenbach, 1976), predictability of target location (Robinson, Koth, & Ringenbach, 1976) and the angle of target eccentricity (Sanders, 1970). Those that affect target processing are not as well defined. Netchine, Pugh, & Gihou (1987) reported that head movements of readers increase in number and magnitude as the difficulty of the text increased. The results are equivocal, however, since they did not control for temporal aspects that may have affected head movements; the readers may have spent more time viewing more difficult phrases, which in turn may have caused an increase in the likelihood of a head movement. Thus, the question remains unanswered regarding the effects of difficulty on amplitude and likelihood of head movements.

The present study examines the relationship between saccade latency to a target and advance knowledge of the time that the target must remain fixated. If saccades are evoked simply by the presentation of a stimulus, then one should see no differences in saccades made to targets when a decision can be made immediately versus one to which the decision must be delayed. If saccades are not merely evoked, but, rather, are influenced by more central processes, such as indicated in the Abrams study referred to earlier (Abrams & Jonides, 1988), then saccades in the delayed condition could start later than those in the no-delay condition. Further, if task difficulty (i.e., that required by the peripheral target) affects head movements, then there should be an increase in the likelihood of a head movement as a task becomes more difficult. This increase would be reflected in an increase in the proportion of gaze shift to-target that is accomplished by the head.

Methods

Subjects. Subjects were 7 volunteers from an Experimental Psychology course at Washington University. None had any apparent visual abnormalities.

Procedure. Subjects were seated in front of a horizontal display of alphanumeric LED units, on which characters could be presented at eccentricities up to 50 degrees. The LED units were mounted behind a 1.3-cm clear slit running horizontally across the length of a 0.6 x 1.9-m black plastic sheet. The sheet was perpendicular to the line of sight, and was flexed into a circular arc of 120 degrees.

Horizontal eye movements were recorded by silver-silver chloride electrodes applied lateral to the outer canthus of each eye. Head movements were detected by a device described at the end of this experiment.

Subjects were run in each of four conditions, two letter identification tasks and two arithmetic tasks. In all conditions, a trial began with a 2,000-ms presentation of an asterisk at the center of the display (0 degrees). In the two letter tasks, 10-ms following the offset of the asterisk, a letter appeared at one of four locations (15° or 50°, left or right of center). In the first condition, the letter was displayed for 1,000 ms, was extinguished for 10 ms, and then was replaced by either the same or a different letter. The replacement letter remained on the display for 500 ms. A 2,000-ms interstimulus interval separated the trials. The second condition was the same as the first except that the initial letter remained on the display for 3,000-ms before the changes. Subjects were asked to lift the left index finger from a response pad if the letters were different, and the right index finger if they were the same. There were 128 trials in each condition. Four subjects started with the 1,000-ms condition and the remaining three started with the 3,000-ms condition.

In addition to the above two letter conditions, all subjects were run in two arithmetic conditions: one easy and one difficult. Ten milliseconds after the offset of the central asterisk, an arithmetic equation was presented, containing either the correct or incorrect solution. The entire equation was presented simultaneously. If presented on the left, the first number of the equation was at 50°; if presented on the right, the last number was at 50°. Subjects were instructed to lift their right index finger if the solution was correct, and their left index finger if the solution was incorrect. There were twenty trials in each condition.

Data were recorded on analog tape and then digitized off-line using a PDP 11/23+ computer. Data from the first and last 40 trials of each experimental session were analyzed.

Results

The first analysis dealt only with the letter identification task. For this purpose, a completely within-subjects ANOVA consisting of three variables: 2 (Eccentricity) x 2 (Delay before decision) x 2 (Time in session) was performed on median saccade latencies. As expected, there was a significant main effect of Eccentricity; saccade latencies to the far targets were longer than to near targets (15°, 178 ms; 50°, 219 ms; $F(1,6) = 60.53$, $p = .0002$). Further, there was a Delay main effect, the longer delay producing the longer saccade latency (1,000 ms: 185 ms; 3,000 ms: 212 ms; $F(1,6)=9.97$, $p = .02$). There was no Time main effect; i.e., saccade latencies early in the experimental session did not differ from those late in the session, nor were there any significant interactions.

The second issue was whether peripheral task difficulty was a factor in determining the proportion of gaze displacement accomplished by the head versus the eye. A one-way ANOVA was performed on the two arithmetic conditions and the longer of the two letter conditions (letter-3,000). The analysis was on the mean proportion of the total eye movement accomplished by the head. As expected, there were significant differences in the proportion of gaze displacement performed by the head $F(2,16)=29.70$, $p < .0001$. Paired comparisons indicated that a greater proportion of gaze displacement accounted for by head movements occurred in both the arithmetic tasks than in the letter task, and the arithmetic tasks did not differ from one another (Easy arithmetic vs. Letter: $t = 5.92$, $p < .0005$; Difficult arithmetic vs. Letter: $t = 7.22$, $p < .0005$; Easy vs. Difficult arithmetic: $t = 1.31$, $p > .05$). The mean proportion of gaze shift accomplished by head movement in the three tasks were, letter: .26, easy arithmetic: .51, difficult arithmetic: .57.

Discussion

The present study replicated the effects of eccentricity, and, in addition, demonstrated that the time delay before a target-related decision must be made, affects saccade onset time. When the subject has prior information that a decision can be delayed (as in the 3,000-ms condition), the eye is somewhat slower to move to the periphery. The eye is not simply obligatorily "pulled" to a stimulus presented in the periphery but is responsive to the nature of the processing to be required by that stimulus. Interestingly, the differences are smaller than one might expect given the amount of additional time subjects have before a decision is required.

This experiment differs from previous eye movement studies in that the subject's head was free to move. Even with this difference, saccade latencies (under the "normal" conditions reported here) do not differ greatly from those reported elsewhere.

The results also suggest that as the task presented by peripheral targets becomes more cognitively difficult, the proportion of gaze displacement accomplished by the head increases. This observation must remain tentative, however. The significant effect was between the letter-3,000 condition and the two arithmetic conditions. Not only did these conditions differ in difficulty, but the time required to accomplish these tasks differed markedly, as one would expect. Thus, whether it is the time *per se*, or the cognitive difficulty that is the controlling factor, cannot be decided at this point. To resolve this issue, a research design is necessary in which time is manipulated independently of difficulty. Such an investigation is in progress.

The present study also demonstrates that the onset of the head and eye movements are closely time locked when acquiring targets at eccentricities of 50 degrees. Under these circumstances, the eye should precede the head (and usually does by about 20 - 40 ms). When making a "predictable" head movement (as in the return movements in the present study) the head should begin to move before the eye. This was not found to be a consistent pattern when subjects returned their gaze to center.

Note: Experiments 2 and 4 of the above series were presented in Boston, at the 30th (1989) annual meeting of the Society for Psychophysiological Research.

Hardware Development for Experiment 4

Electronics.

An infrared-emitting light source was mounted on a bar attached to the top of a bicyclist's helmet so that the light pointed to 0° when the subject looked straight ahead. Photocell devices maximally responsive to infrared light are mounted approximately equidistant from the light source on the left and right shoulders. The output from each photocell can be independently amplified so that equal amplitude head movements to the left or right produced the same voltages before integrating voltages from the two circuits. Overall sensitivity can be manipulated by another stage of amplification.

Calibrations.

Two levels of calibration are used. The first utilizes a "dummy" head (a milliner's head). The helmet is placed on

the head and the latter placed at the location normally associated with head position. The head is swiveled to the desired angular deviation for a number of trials to allow for equating left and right deviations. A small flashlight focussed to a small beam is clipped to the helmet and oriented forward towards the display. Visual angle can thus be defined by projecting the light onto marked points on the display, or activating letters on the display, corresponding to several visual angles.

The second level of calibration is "subject" determined. Such calibration is conducted at the end of the experimer runs. It involves both calibration of the head movement device as well as calibration of the EOG outputs. To calibrate the head movement output, subjects are instructed to aim the light at the position where stimuli were previously presented. To calibrate the EOG, subjects are instructed to keep the light focussed at the central location and use only their eyes (no head movement) to acquire information from the peripherally presented targets.

Head Movement Detection Algorithm.

A rudimentary, but functional, algorithm has been designed and implemented that allows for identification of the following time points:

1. initiation of head movements to a target.
2. peak head movement to a target.
3. initiation of head movements returning the head to central fixation.
4. termination of return head movement.

GENERAL SUMMARY AND DISCUSSION

It has been amply demonstrated that blink inhibition is associated with the anticipation of stimuli that require processing. The interpretation that served as the basis for the first study of the present effort was that this anticipatory blink inhibition reflects a growing attentional mobilization as a task stimulus approaches. If preparation for stimulus input leads to a decline in blinking, then it would appear to follow that the presence of blinks in temporal association with task stimuli would signal an attentional lapse. If so, blinks could be used to predict, and thus prevent, performance dropouts associated with suc attentional dropouts.

Although clearly reconfirming the anticipatory inhibition effect, the results of the first study lend no support to the prediction that blink occurrence predicts a discrimination error. Blinks were no more likely to occur in association with such errors than with stimuli that were judged correctly. The hypothesis fared no better when the analysis was restricted to those errors attributable to attentional

dropouts. Clearly, the relation between blink occurrence and attention is more complex than hypothesized.

The second study was designed to explicate the relation of cognitive processes to blink occurrence and to further explore the effect of difficulty on blink latency. Target stimulus duration differed for each of a series of four tasks, whereas the longer nontarget stimulus duration was the same for all tasks. It is obvious that on *nontarget* (longer) trials of this task, judgment of stimulus duration cannot be made until after the target duration had elapsed. Given the hypothesis that blinks are inhibited until after the discrimination is made, the prediction was that the latency of the first blink following the onset of the *nontarget* stimulus would be a function of the duration of the *target* stimulus in that task.

Results were consistent with the hypothesis; blink latency on *nontarget* trials was a linear function of *target* duration. On the other hand, the function relating blink latency to target stimulus duration was not linear, which is interpretable as a difficulty effect. As an alternative, it was suggested that this was a foreperiod effect. Accordingly, the onset of the target stimulus is serving functionally as the warning stimulus and the offset of the target stimulus serves as the imperative stimulus in a choice reaction time experiment. The data suggest that 220 ms may be the optimal warning duration under the conditions of these tasks. This interpretation could be tested by increasing the duration of the nontarget stimulus to a value in the 1 or 2 sec range, making it functionally close to a simple reaction time task with catch trials. If difficulty were the critical variable, these procedures would reduce or eliminate the target duration effect.

The third study was designed to separate the contributions of the various processes affecting blink latency and to assess the role of each in the change in blink latency from early to late trials. The hypothesis was that the decline in blink latency over trials was due to an increase in the efficiency of the process by which the instructional rules guiding the performance (the so-called "Rule Invocation", or "RI", process) of the task are implemented. It was further hypothesized that this effect would only be manifest when the baseline blink latency was high enough initially, thus allowing latitude to decline. This objective could be accomplished, for example, by requiring subjects to respond, or by increasing the difficulty of the task.

There were three conditions in this experiment, designed to separate the potential contributors to blink latency. In general, the results of experiment 3 provide reasonable support for the hypothesis that processes prior to those related to response programming and execution are the basis

of the decline in blink latency over time. When baselines are sufficiently high due to the complexity of the task or the requirement to respond, there is a decline with time. What happens when there is no strong RI component and there is a response required is less clear.

In the above analyses, the maximum blink latency allowed into the analysis was systematically varied. It was recognized that this procedure introduced an *ad hoc* element into the analysis. It did highlight the fact, however, that the period sampled can be critical in demonstrating the effect of some variable. For example, if some cognitive process occurs relatively late after stimulus presentation, inclusion of blinks that occur before the occurrence of that process, or after it has terminated, tends to mask the blink latency effect of that process. One solution would be a more detailed analysis of blinks, examining them as a function of discrete latency bins.

With respect to time effects, or interactions involving time, in experiment 3, it will be recalled that the sampling period was extended to 15 minutes (from 5 in other studies). It was recognized that as a consequence, the early sample was separated from the late sample by only 10 minutes. A 15-minute sampling period, then, would tend to reduce time effects. Nevertheless, the extension was designed to provide an adequate number of blinks for all conditions. Since several variables were pooled rather than being treated as variables in the analysis (e.g., side of stimulus presentation) the extended period proved to be unnecessary. It is possible that redigitization of the data using conventional time periods followed in this laboratory might reveal effects that were masked in the extended period.

Experiment 4 addressed the question of whether saccades are automatically evoked by peripheral stimuli or whether saccade latency can be affected by modulating central processes. This hypothesis was tested by assessing the effects on saccade latency, of foreknowledge of the time that a peripheral stimulus must remain fixated. Results suggest that the eye is not simply obligatorily "pulled" to a stimulus presented in the periphery but is responsive to the nature of the response required by that stimulus.

The results also suggest that as the task presented by peripheral targets becomes more cognitively difficult, the proportion of gaze displacement accomplished by the head increases. This observation must remain tentative, since not only did the conditions differ in difficulty but the time required to accomplish these tasks differed markedly, as one would expect. Thus, whether it is the time *per se*, or the cognitive difficulty that is the controlling factor can not be decided at this point. To resolve this issue, a research

design is necessary in which time is manipulated independently of difficulty. Such an investigation is in progress.

REFERENCES

Abrams, R. A. and Jonides, J. (1988). Programming saccadic eye movement. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 428-443.

Bartz, A. E. (1962). Eye movement latency, duration, and response as a function of angular displacement. *Journal of Experimental Psychology, 64*, 318-324.

Bauer, L. O., Goldstein, R., and Stern, J. A. (1987). Effects of information-processing demands on physiological response patterns. *Human Factors, 29,* 213-234.

Bauer, L. O., Strock, B. D., Goldstein R., Stern, J. A., and Walrath, L.C. (1985). Auditory discrimination and the eyeblink. *Psychophysiology, 22*, 636-641.

Bernstein, A. S., Taylor, K. W., Weinstein, E. and Riedel., J. (1985). The effect of stimulus significance on relatively sustained (tonic-like) and relatively transient (phasic-like) aspects of electrodermal, heart rate, and eyeblink response. *Biological Psychology, 21,* 183-228.

Brezinova, V., and Kendell, R.E. (1977). Smooth pursuit eye movements of schizophrenics and normal people under stress. *British Journal of Psychiatry, 130, 59-63*.

Carpenter, A. (1948). The rate of blinking during prolonged visual search. *Journal of Experimental Psychology, 38,* 587-591.

Findlay, J.M. (1981). Spatial and temporal factors in the predictive generation of saccadic eye movements. *Vision Research, 21,* 347-354.

Goldstein, R., Walrath, L. C., Stern, J. A. and Strock, B. D. (1985). Blink activity in a discrimination task as a function of stimulus modality and schedule of presentation. *Psychophysiology, 22*, 629-635.

Hoffman, A.C. (1946). Eye movements during prolonged reading. *Journal of Experimental Psychology, 36*, 95-118.

Houtmans, M.J.M. and Sanders, A. F. (1984). Perception of signals presented in the periphery of the visual field. *Acta Psychologica, 55*, 143-155.

Näätänen, R. and Merisalo, A. (1977). Expectancy and preparation in simple reaction time. In S. Dornic (Ed.). Attention and performance VI. (pp. 115-138) Hillsdale, NJ: Erlbaum

Netchine, S., Pugh, A. K., and Gihou, M-C. (1987). The organization of binocular vision in conjunction with head movement in French and English readers of 9 and 10 years. In J. K. O'Regan and A. Levy-Schoen (Eds.), Eye Movements: From Physiology to Cognition. North-Holland: Elsevier.

Orchard, L.N., and Stern, J.A. (1991). Blinks as an index of cognitive activity during reading. Integrative Physiological and Behavioral Science, 26, 108-116.

Robinson, G. H., Koth, B. W., and Ringenbach, J. P. (1976). Dynamics of the eye and head during an element of visual search. Ergonomics, 6, 691-709.

Sanders, A.F. (1970). Some aspects of the selective process in the functional visual field. Ergonomics, 13, 101-117.

Saslow, M. G. (1967). Latency for saccadic eye movement. Journal of the Optical Society of America, 57, 1030-1033.

Siegmund, H., Stoppa, M., and Santibañez-H, G. (1987). Eye and head movements to visual and auditory targets. Activitas Nervosa Superior, 29, 73-82.

Stern, J. S., Walrath, L. C. and Goldstein, R. (1984). The Endogenous Eyeblink, Psychophysiology. 21, 22-32.

White, C. T., Eason, R. G., and Barlett, N. R. (1962). Latency and duration of eye movements in the horizontal plane. Journal of the Optical Society of America, 52, 210-213.

Wibbenmeyer, R., Stern, J.A., and Chen, S.C. (1983). Elevation of visual threshold associated with eyeblink onset. International Journal of Neuroscience. 18, 279-286.

Zambarbieri, D., Schmid, R., and Ventre, J. (1987). Saccadic eye movements to predictable visual and auditory targets. In J. K. O'Regan and A. Levy-Schoen (Eds.), Eye Movements: From Physiology to Cognition. North-Holland: Elsevier.